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DEVELOPMENT OF A FORCED ENTRY MISSION OBJECTIVE SELECTION ALGORITHM FOR IMPLEMENTATION INTO THE JOINT WARFARE ANALYSIS EXPERIMENTAL PROTOTYPE

by

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ABSTRACT

This thesis develops an algorithm for the selection of objectives for forced entry military operations in a theater level campaign model. The Joint Warfare Analysis Experimental Prototype (JWAEP) is an interactive, 2-sided, theater-level combat model based on an arc-node representation of ground, air, and littoral combat. It may be used in an interactive gaming mode or a closed-form stochastic analysis mode. The need for active mission assignment in the analysis mode mandates that objectives for combat operations be nominated during each planning cycle to adapt to the changing face of the battlefield. JWAEP would execute an initial feasibility check for enemy occupied or controlled nodes against the assets available to the friendly forces. Based on the probabilistic representation of the enemy units occupying a node, the algorithm determines the relative value of perceived maneuver units and static targets. This is then compared to the relative perceived strength of the units in that node and surrounding nodes which may also defend against the operation. The perceived strength determines the threat; it is calculated for each force capable of executing the attack. The most desirable node for each force, given value and threat, is sent to the appropriate planning module. The principal focus of this thesis is on the determination of the target value parameter and the node defensibility parameter as they are used to nominate and rank possible objectives.

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EXECUTIVE SUMMARY

The Joint Warfare Advanced Experimental Prototype (JWAEP) represents an attempt by the Naval Postgraduate School's Department of Operations Research, under the sponsorship of the Directorate for Force Structure, Resources, and Assessment (J-8) of the Joint Chiefs of Staff and the U.S. Army Training and Doctrine Command (TRADOC), to improve existing techniques of modeling joint theater level combat. The ultimate goal of JWAEP is to fully represent the dynamic, uncertain, and stochastic nature of combat at the theater level. It is intended be a fully capable simulation which requires little or no input from human operators during execution when operating in a systemic analysis mode.

One specific need to accomplish this goal is the ability for the model to assign missions to units during execution. The assignment of a strategic or theater mission may be driven by factors external to the model. The model, however, must develop intermediate missions and objectives which help accomplish those strategic goals. These intermediate missions may include offensive operations, defensive operations, raids, and forced entry missions.

A forced entry mission attempts to insert a large number of friendly combat forces into enemy occupied or controlled areas for the purpose of securing those areas for further operations. The amphibious assault, the airborne assault, and the air mobile assault are the three primary types of forced entry missions. During a campaign, an operational commander may use the amphibious, airborne, or air mobile forces in order to seize entry ports, establish air heads, or create an additional threat to the enemy from an unexpected direction. These missions will require an objective to act as the focal point for the maneuver forces.

The choice of a mission objective should reflect the operational commander's desire to control that area and its immediate surroundings. There will be three principal considerations for the selection of the objectives. The first is a measure of how much the maneuver commander desires the occupation or control of the area, either for his own purposes or to deny the enemy its use. It is his perception of its value. The second is a measure of how important that area is to accomplishing the strategic goals of the campaign. The third is a measure of how much force the enemy is willing to expend in order to maintain control of that area.

The value of an objective can be broken into four principal categories: military, political, economic, and social. Each location or unit will have some value from these four categories due to either infrastructure or enemy units present. It will be up to the operational commander and his staff to assess each of the four values for each unit or location as well as the perceived assets of enemy units in the area. By combining these values for all four categories in a manner that captures their relative importance, a single number for each objective can be used to compare it against all other possible objectives. Higher value at a potential objective implies a greater desire to prosecute that objective.

The importance of a particular area relative to the strategic goals may be a function of how close the operational objective is to the seat of power or control for the enemy nation (which may be a strategic objective). Comparing the distance from the operational objective to strategic objective to the distance from current friendly positions to the strategic objective gives a relative measure of the benefit gained from each objective over the current situation.

The final consideration, the estimate of enemy forces that can defend an objective, is based on the size and type of enemy units perceived in the area. Units in nearby areas may affect the estimate and are included in the calculation of defensibility for each objective.

This thesis presents an algorithm that evaluates each of these three measures (value, strategic importance, and defensibility) and then combines them to determine the most desirable forced entry mission objective. The algorithm uses the representations of the perceptions of enemy units that are unique to JWAEP.

After determining which areas are eligible for the different forced entry mission types, the algorithm computes each of the three measures for these potential objectives. The value calculation is essentially a weighted sum of all of the types of value possessed by the units and infrastructure at each objective. The weights represent the operational commander's relative importance of each of the value types. The total value for a specific objective will come from three sources: the enemy units located on the objective, the infrastructure on the objective, and the inherent value possessed by the objective itself. Since exact enemy locations are not always available to a decision maker, the algorithm computes an expected enemy unit value in each of the four value categories. This is done using the perception probabilities which JWAEP uses to represent the current estimate of

the size and type of enemy forces at a specific location. The strategic importance calculations use straight forward methods to determine the relative advantage one operational objective has over another in regards to the location of the strategic objective.

The defensibility parameter of each potential objective is calculated using the estimate of the number of combat assets in and around that objective as determined from sensor detections represented by JWAEP. These detections have associated with them a measure of uncertainty that can be used to produce a conservative estimate of the number of assets that could be present on the objective when the mission is executed.

Each of these three parameters (value, strategic importance, and defensibility) are then combined by first converting the parameter values to a common scale of measurement and then uses a weighted sum to produce a single measure of desirability. The weights can represent the operational commander's relative concern with each of the three measures. If he is extremely ambitious, he may not include the enemy defenses in the overall desirability calculations. If he is overly cautious, he may use only the defenses to determine the best objective.

The analysis indicates that the algorithm properly evaluates these parameters for a small group of objectives and, depending on the weights used, produces logical preference rankings for the objectives. In the cases examined, the outcomes are consistent with the "common-sense" choices that would have been made. Additionally, an examination of the impact of varying certain parameters that are used in the algorithm was made. In general, the changes produced were consistent with conventional wisdom; however, in some cases the magnitude of the effect was less than was expected.

Overall, the algorithm appears to work properly for the small test scenario. The results, however, require careful examination because the output values can be nearly equal. Thus, while one may be higher, it is important to take into account the magnitude of the difference before just choosing one as the "best". In some cases, two or three objectives might be considered equally desirable and further analysis should be conducted prior to final selection of the sole mission objective.

I. INTRODUCTION

Since the genesis of the computer age, the United States Department of Defense has relied heavily on computers to improve all aspects of its operations and functions. While computers have become indispensable time savers in matters of pay procedures, record keeping and day to day administrative functioning, the truly great benefits have been seen in the operational areas of the Department of Defense. Computer technology has made communications more reliable, aircraft safer, and weapons deadlier; but alongside these tangible improvements, the ability to model future operations and predict their outcomes has emerged. Computer wargames can create notional battlefields and allow decision makers to practice fighting wars without risking human lives. Computer simulations can help determine organizational shortfalls and even predict the combat effectiveness of a weapon system not yet manufactured. They have been used to predict the outcomes of major land battles, modify existing campaign plans, and examine the capabilities of the forces or equipment expected to fight in future conflicts.

The Joint Warfare Advanced Experimental Prototype (JWAEP) represents an attempt by the Naval Postgraduate School's Department of Operations Research, under the sponsorship of the Directorate for Force Structure, Resources, and Assessment (J-8) of the Joint Chiefs of Staff and the U.S. Army Training and Doctrine Command (TRADOC), to improve existing techniques of modeling joint theater level combat. The ultimate goal of JWAEP is to fully represent the dynamic, uncertain, and stochastic nature of combat at the theater level. It is intended be a fully operational simulation which requires little or no input from human operators during execution.

One specific need to accomplish this goal is the ability for the model to assign missions to units during execution. It is not sufficient to assign a general "attack" mission

for all units in the model, as there should be larger operations that will need more complex orders to better simulate realistic campaign operations. In order to make the model more robust in the creation, planning, and execution of different offensive missions, the ability to designate an objective becomes paramount. The assignment of a strategic or theater mission may be driven by considerations external to the model, but the model must develop intermediate missions which work toward accomplishing the strategic goals. These intermediate missions are the responsibility of the operational commander or similar entity represented in the model. The decisions that he makes should be made by any theater level model that strives to be systemic, or closed, in its decision making process.

A. PURPOSE

The purpose of this thesis is to develop a method for nominating potential objectives for operational forced entry missions and then rank ordering them by preference. These initial rankings could then be used to provide mission objectives to different planning modules to determine which are considered both feasible and most desirable. The primary considerations for choosing a mission objective are the value the area has to the enemy's ability to prosecute the war and the extent to which he will defend that ability. The choice becomes a decision made to satisfy two competing desires of the operational commander: conduct operations that will result in the defeat of the enemy and safeguard the lives of the personnel under his command. It is not easy to strike a balance between them.

A method for measuring advantage gained against the risk involved is needed to compare perceived value of a given area in the theater possessed by the enemy against the estimated defensive capability present. This thesis investigates one method of measuring value, strategic importance, and defensibility which is flexible in its implementation.

B . FORMAT

Chapter I has presented a brief description of JWAEP and the specific purpose of this thesis.

Chapter II presents the necessary background in warfare principals concerning campaign operations in a theater-level conflict and a more detailed review of JWAEP and its capabilities and advantages over other models currently in use by most of the services. The definitions of some of the terminology and parameters which are new to the JWAEP lexicon are also presented.

Chapter III describes the specific steps taken by the algorithm to nominate and prioritize target areas for further analysis. The necessary additions to the JWAEP database are also discussed.

Chapter IV presents the initial analysis of the results of using the algorithm on a small network. The purpose is to investigate the impact of changing the input parameters for the algorithm and to verify the output rankings as much as possible.

Chapter V contains the conclusions and recommendations for future work. Further areas of study will be addressed, both in an effort to improve this specific research area as well as the entire JWAEP model in general.

II. BACKGROUND

A. WARFIGHTING PRINCIPALS AND TERMS

It is important to be thoroughly versed in the terminology and current doctrine of warfare in order to model it properly. The following terms are the principal concepts that encompass operational mission assignment.

1. Strategic Level

While the word "strategy" is routinely used by society to describe a plan of action in any circumstance, for military leaders it has a very explicit meaning. The term "grand or national strategy" refers to the activities a nation undertakes that strive to attain the objectives of policy, in peace and in war [Ref. 1: p. 3]. All of the resources of a nation are included, not just its military. In a democracy, policy (and therefore national strategy) is exclusively in the realm of elected and appointed officials. The concept of "Military Strategy" brings the execution of policy into the arena of specific military actions. Here the use of force, or at least the threat of force, is the principal tool.

The strategic level of war is the level at which a nation (or a group of nations in a coalition) determines national (or multi-national) security objectives and uses its (or their) national resources to accomplish these objectives [Ref. 2: p. 363]. The strategic level involves the development of war plans, the selection and deployment of forces, and the determination of military objectives which will directly assist in achieving political and military aims. In the United States, these decisions are typically made by senior elected officials (most notably the President), Presidential appointees, and the senior leadership of the Armed Forces.

2. Operational Level

The operational level of war acts as the link from the policy makers and strategic decisions to the warfighters and tactical decisions. It is the level at which campaigns and major operations are planned, conducted, and sustained to accomplish strategic objectives within theaters or areas of operations [Ref. 2: p. 275]. The ultimate goal of operational commanders is to achieve the established strategic aim through the planning, coordination and execution of tactical missions. Traditionally, an operational level of command is within the purview of one of the Commander-in-Chiefs (CinCs) of the Unified Commands who will report directly to the National Command Authority (NCA).

3. Tactical Level

The tactical level of war is the level at which battles and engagements are planned and executed to accomplish military objectives assigned to tactical units or task forces [Ref. 2: p. 376]. It is where a force applies its combat power directly against its opponent. It is the world of combat [Ref. 1: p. 5]. On the tactical level, the interaction between opposing forces is measured in meters, seconds, and most importantly, lives. For the infantry, tactical fundamentals exist in the domain of the fire team of four soldiers, through the battalion of 600 soldiers, and possibly up to the division of 15,000 soldiers. In general, tactics are the tool of the trigger puller, whether of a rifle, a missile, or a torpedo.

4. Interaction and Overlap

The translation between the levels of war and the levels of command is one that must be done with each new conflict or scenario. The only constants exist at the extremes; the highest level of strategy coming from the leaders of the nations and the lowest level of tactics at the individual soldier. In relatively minor conflicts or small-scale contingency

missions, the strategic and tactical levels may meet at the task force commander who would be in direct contact with the NCA and in direct command of the combatants. For Major Regional Contingencies (MRCs), the operational level would widen to include Corps and Army levels of command.

A notable characteristic of the separation of the three levels of war is the impact of success and failure in each. Tactical success does not automatically guarantee the accomplishment of the strategic aims and tactical incompetence will not always deny them; however, there is a strong correlation. Similarly, the failure to clearly identify strategic goals makes their necessary translation to military missions and objectives a futile task. The operational level must synthesize the tactical results to create the military conditions that induce strategic success [Ref. 1: p. 87].

5. The Operational Commander

Between the two extremes of strategy and tactics, the operational commander must refine military objectives as strategy changes and must also attempt to influence strategy if the tactical goals become impossible to meet. He must strike the balance between resources provided and forces committed, between political and social concerns and the security of his charges, and between current and future combat. Ultimately, it is he who must bridge the span between "the lofty heights of strategy" and the gritty reality of tactics in combat [Ref. 1: p. 6].

This importance of the operational decision maker translates directly into the need for the representation of a similar entity in a theater level model. It is not sufficient to have a vast array of units on a battlefield where they fight as autonomous combat elements engaging each other without a coherent operational plan. A force that fights in a clear, coordinated manner will have a decided advantage over one that does not. The application of combat power at a specific place and time can result in success, even for an outnumbered

force in unfamiliar territory. The operational commander must orchestrate the use of all his assets — ground combat units, air forces, reserve forces, logistic units, and other supporting forces — to achieve success in a theater-level campaign. It is through the efficient integration of all these forces that success is achieved most rapidly.

6. Maneuver Warfare

Maneuver warfare is a warfighting philosophy that seeks to shatter the enemy's cohesion through a series of rapid, violent, and unexpected actions which create a turbulent and rapidly deteriorating situation with which he cannot cope [Ref. 3: p. 59]. The principal elements of maneuver warfare include speed, surprise, flexibility, initiative, and intensity. Decentralized decision making enables the maximum degree of speed and flexibility on the battlefield.

a. Decision making

The heavy emphasis placed on decentralized decision making requires clearly defined commander's intent to allow his forces to act and react quickly on the battlefield in order to shape the battle toward his vision of the final result. Paramount to the success of a unit in combat is the ability to rapidly make decisions, capitalizing on situational awareness and opportunity, not focusing on lock step procedures known by rote. Decisions must be made in light of the enemy's anticipated reactions and counteractions, recognizing that while we are trying to impose our will on the enemy, he is trying to do the same to us [Ref. 3: p. 68]. By consistently making decisions faster than our opponent, we achieve an advantage in initiative which carries over to an advantage which impacts the entire conflict. The four-step mental process of decision making, as set forth by Colonel John Boyd, USAF, is the Observation, Orientation, Decision, Action (OODA) loop as shown in Figure 1 [Ref. 3: p. 84]. The faster a commander moves

through his decision-making cycle (i.e., a smaller OODA loop), the more he imposes his will on the enemy. If his loop is consistently tighter, he overwhelms the enemy with his force's actions and paralyzes their ability to fight.

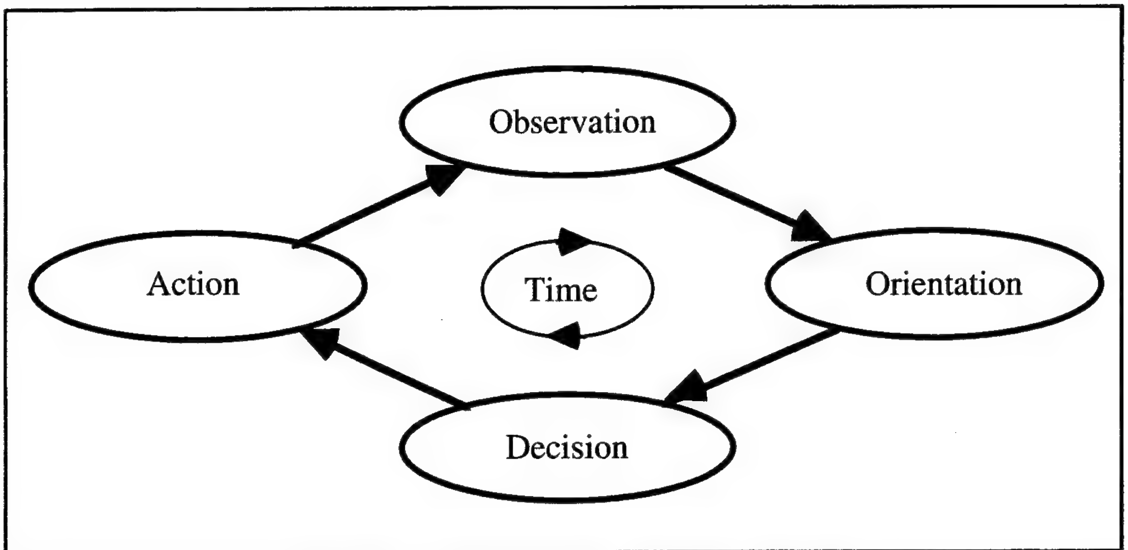

Figure 1. Boyd Cycle (OODA Loop)

b. Uncertainty

With the inherent uncertainty in combat operations, perfect information is not available to make "perfect" decisions. The desire, then, is to make decisions involving acceptable risk and to continue to do this faster than the enemy. To quote Gen. George S. Patton, USA :

> "A good plan violently executed *now* is better than a perfect plan executed next week." [Ref. 3: p. 70]

Uncertainty on the battlefield directly affects the Observation and Orientation phases of the decision making cycle. If a commander is able to "see" the situation more clearly than his opponent, he can orient more quickly and his decisions will have even greater effect. Since both sides in a conflict experience this "fog of war", the advantage will be gained by the side that accepts its inevitable presence and has trained to make

decisions in light of it. Waiting until a situation has unfolded completely is a guaranteed recipe for failure on the battlefield.

7. Centers of Gravity

The strategic center of gravity is traditionally the enemy's capital city; however, this need not be always the case. According to Karl von Clausewitz:

> "Out of these characteristics a certain center of gravity develops, the hub of all power and movement, on which everything depends. That is the point against which all our energies should be directed." [Ref. 4: p. 595-596]

In a theater level conflict, it is unlikely that the strategic center of gravity would change rapidly during the conflict. It is important to remember that the strategic center of gravity may not coincide with the operational centers of gravity at a given time. The operational centers of gravity are often the enemy forces which prohibit either the seizure of the strategic objective or accomplishment of the strategic goals. If the capital city is heavily defended by the military forces, then they may coincide.

If the strategic goal of the campaign is the destruction of the enemy's military power, the center of gravity may be the upper levels of its military leadership or a particular unit. A Cold War era, Central Europe scenario might have suggested an enemy center of gravity of the Warsaw Pact forces. Rather than attacking this center of gravity directly, the neutralization of the forces could be attained by aggressive attacks on the command and control or logistics structure that support the actual combat forces. [Ref. 5: p. 100]

8. Forced Entry Mission

The goal of a forced entry mission is to establish a force in enemy controlled territory in order to prosecute operations intended to strike specific targets. The principal

methods of executing a forced entry mission are the amphibious assault, the airborne assault, and the airmobile assault.

a. Amphibious Assault

The amphibious assault is an amphibious operation that involves establishing a force on a hostile or potentially hostile shore [Ref. 2: p. 25]. The forces involved are initially embarked on naval vessels and may be transported by surface (landing) craft, aircraft (helicopters), or a combination of the two. Amphibious forces provide the operational commander substantial combat power with superior flexibility in its employment.

A major assault would require the use of both air and surface means to offload in order to build combat power as quickly as possible. In standard U.S. Marine Corps amphibious operations, a significant portion of the infantry unit comprising the ground combat element (GCE) will fly in aboard helicopters and the remaining infantry and heavier combat power (light armored vehicles, artillery, combat engineers, etc.) will come ashore at the beach. The two groups can then consolidate and continue to the objective by both air and ground maneuver.

For smaller objectives requiring fewer total forces ashore, helicopter assets may be sufficient to conduct the assault. The use of air assets alone provides an increase in speed and surprise at the cost of combat power. Traditionally, amphibious raids are the only missions which use only aircraft to bring the combat units ashore. The transportation of amphibious forces by aircraft alone is very similar to an airmobile assault in both the planning and execution. For the purposes of this thesis, an amphibious assault implies an air and surface offload.

b. Airborne Assault

The airborne assault is characterized by the use of parachutes to debark aircraft over a designated drop zone. In general the primary threat to an airborne force prior to debarking the aircraft is the enemy's air defense units. The principal advantage is the speed that a very large force can insert and consolidate on an objective. The U.S. Army's 82nd and 101st Airborne Divisions train to insert as a division, if required. However, there is the added requirement for air superiority over the area of operations, considering the vulnerability of the large transport aircraft needed. Prior coordination with the air forces providing the aircraft and greater troop preparation is also required. The mission must originate at a suitable airfield which adds to the restrictions of this type of assault.

c. Airmobile Assault

The airmobile assault differs from the airborne assault primarily in the transports used and the insertion technique. The combat forces are lifted by helicopter from secure areas and transported to the landing zone. This method may require less troop preparation and interservice coordination, but the trade-off is the size force that can be lifted and the longer time required to amass combat power on the ground. While air supremacy is always desired, helicopters are capable of more tactical movement which can enable missions under less favorable conditions.

9. Course of Action

In general, the term "course of action" implies a plan or scheme designed to accomplish a specific mission. There may be many courses of actions proposed for a single mission. Traditionally, the concept of operations is the portion of a COA which describes how the mission is to be executed and by what type of forces. Courses of action are intentionally broad outlines of the mission that do not delve into detailed actions by

specific units. Their purpose is to provide a starting point to evaluate the feasibility, supportability, sustainability, and overall tactical soundness of each plan. Once approved, a particular COA becomes the basis for the development of an operation plan or operation order [Ref. 2: p. 97]. It is important to understand that a course of action is a framework for the general scheme of maneuver to accomplish the mission.

10. Objective

Here again, there is a subtle difference between common usage in society and that by the military. An objective is generally thought to be any goal or desired result. For military commanders, an objective is a defined geographical area whose seizure or holding of which is essential to the mission [Ref. 2: p. 271]. While maneuver warfare has moved combat doctrine from a terrain based philosophy to one which focuses on the enemy forces, the need to determine objectives by an operational commander remains important. Taking a hill or seizing a town are not missions in and of themselves, but they are valid intermediate steps in waging campaigns against the enemy. In many offensive operations, attriting the enemy with a minimum of friendly casualties is one of the primary goals; owning territory is not. It is important to add, however, that in the defense, certain terrain types can greatly enhance one's ability to fight (e.g., possession of high ground overlooking the enemy's only avenue of approach). Since a campaign can often be characterized by a cycle of offensive and defensive postures, the seizure of intermediate objectives may be considered a mission even if it is not the ultimate goal.

For a forced entry mission, the objective serves as the area of focus for movement and consolidation. Traditionally, the point of entry is not the objective itself. Operational Maneuver from the Sea (OMFTS) is the current U.S. Marine Corps philosophy for amphibious operations and has incorporated the maneuver warfare doctrine. It is explicit in moving away from "ship-to-shore movement" and moving to "ship-to-objective

maneuver". The primary difference lies in the importance of the beach. It is no longer a stopping point; rather it is merely a small portion of the path to the objective and selection of the beach is simply a by-product of the selection of the most desired route based on enemy strengths and weaknesses. With the capability provided by the Landing Craft, Air Cushion (LCAC) and the Assault Amphibious Vehicle (AAV), a Marine Expeditionary Force (MEF) is capable of moving a considerable distance inland to an objective.

The selection of a drop zone for airborne missions and landing zones for air mobile missions will depend primarily on the location of the enemy units in the vicinity of the objective. Since these light units cannot be expected to cover large distances, the entry points must be relatively close to the objective. Additionally, for these two missions, the use of the objective as the actual drop or landing zone potentially provides some level of surprise and may initially confuse the enemy; but if the mission is detected or compromised, there can be grave results.

In general, surprise is the crucial element for success in the insertion phase of any forced entry mission. It is here that the assault force is most vulnerable. Only when the force is consolidated on the ground or ashore can it fully defend itself. For this reason, most assaults will be supported as much as possible with naval surface fire support, close air support, and indirect fire.

B. COMBAT MODEL TERMS AND TECHNIQUES

The different methods of modeling combat have characteristics which are fundamental in determining the appropriate uses of them. Key terminology for describing various types of combat models is described below.

1. Resolution

The limitations of computer hardware have restricted the current family of combat models into two primary groups. High resolution models represent each individual and weapon in a tactical battle and resolve each shot between the combatants to assess attrition and ultimately determine mission success or failure. At present, high resolution models are not usually capable of modeling units larger than battalion size before becoming computationally overwhelmed. Low resolution models aggregate the individuals and weapons into units and resolve combat engagements using estimates of attrition between the units, not the individuals. These attrition estimates may come from high resolution model analysis. These models allow larger units to be represented so operational procedures can be analyzed and improved.

Even the capabilities of today's most powerful computers do not allow the modeling of a full theater level conflict from the CinC down to the individual soldier. The sheer number of variables for this undertaking is staggering. A theater level conflict is the result of thousands of individuals interacting at numerous levels. Each individual uses the single most powerful processor available (the human brain) to make decisions with uncertain information from continually changing conditions, incorporating intuition, training, and past experiences. To recreate all of these factors in any reasonable form would stretch not only the limits of the hardware available, but would take years to program and execute to generate any significant results.

Clearly, a complete high resolution model of theater-level combat will not be possible for many years, if ever. As technological improvements are made, the unit size to which a high resolution model is limited may increase. However, as the level of command becomes higher, there are more considerations than just tactical use of weaponry in a given environment. Current high resolution models generally incorporate only rudimentary maneuver tactics. At battalion and regimental levels, the impact of maneuver becomes

much more important. The increasing level of command also brings with it greater concern for the operational and strategic influences in combat.

Despite paring down the realism of a combat model and simulating complex processes, a low resolution model can still produce valuable results and insight into the effect of certain decisions or the impact of specific organization or equipment improvements.

2. Uncertainty

In real combat, there are numerous sources of variation; most notably the differences among human commanders making decisions, equipment effectiveness and reliability, and the effect that external factors such as the terrain and weather can have on combatants. In most cases the underlying causes for the external variations are themselves complex systems. Their effects are often approximated in a combat model through the use of probability distributions which resemble the variations as much as possible. Stochastic models allow for the variation in outcomes between different runs of a particular scenario which attempt to represent the uncertain nature of combat. Deterministic models are those whose outcomes do not change for a given set of the input parameters.

High resolution models frequently use random processes to model combat at the individual level. Weapons will have parameters such as hit probabilities and kill probabilities for specific types of engagements. During a run of the model, random numbers will be drawn to determine if a shot actually hit the target and if it subsequently killed the target. This is termed a "Monte Carlo" draw and is the simplest form of stochastic modeling. Since every run's outcome depends on the sequencing of numerous random number draws, the outcomes will vary as long as the numbers are truly random and not a reproducible series. JANUS(A) is an example of a stochastic, high resolution

model in use by many agencies throughout the Department of Defense and in the U.S. Army, in particular.

Most of the early theater level (low resolution) models in use by the Department of Defense were deterministic, which means they did not allow for random factors to affect any portion of their execution. As computer technology and model sophistication has improved, some stochastic models have been developed. TACWAR is a deterministic theater level combat model which is primarily operated by the Warfare Analysis Division (WAD) of the Joint Chiefs of Staff and by the analysis cells of the unified commands. It is a very comprehensive model which includes tube and rocket artillery, aircraft, logistics units, and even nuclear and chemical weaponry; but it ignores the uncertain nature of combat by using only deterministic algorithms. [Ref. 6]

Concepts Evaluation Model (CEM) is also an example of a deterministic, low resolution model, used primarily by the Concepts Analysis Agency (CAA) of the U.S. Army. More recent attempts to make CEM incorporate uncertainty have resulted in a model called Stochastic CEM (STOCEM) with limited results [Ref. 7: p. 15]. The transition from a deterministic model to a truly stochastic model involves more than just adding a few random processes. It was partly for this reason that the Joint Chiefs of Staff, TRADOC, and the Naval Postgraduate School started from ground zero in sponsoring the Future Theater Level Model (FTLM) research which has lead to an experimental prototype, called JWAEP. [Ref. 8: p. 4]

One of the principal advantages of the explicit representation of uncertainty in combat modeling in an interactive mode is the effect on the users. As they become accustomed to seeing the "fog of war" on their computer screen, they accept the need to make decisions without perfect information and hopefully become proficient at it. A great shortcoming of models that display ground truth is that they present the decision maker with arguably more intelligence information than they would ever have during actual

combat. In order to "train like we fight", it seems clear that we must strive to hone those skills that will be most frequently used in real combat operations. For the commander, this means making good decisions, even when there is less information available than desired and ultimately using uncertainty to his advantage as much as possible.

3. Decision Making

The distinction between a wargame and a simulation stems from the method by which decisions are made and the purpose of the exercise. A wargame requires human interaction in the form of direct input at different points of the conflict. The purpose is to evaluate the outcome of the battle as a function of the decisions made and to improve the individual decision maker's ability to function under extreme or uncertain situations. Lessons can be learned from actions taken in the wargame and insights can be gained into how decisions are best made. Wargames are often termed "man-in-the-loop" or "interactive" models. Because this type of model solicits information from the user, it is inherently stochastic because two separate runs of the wargame will rarely be identical unless the user makes identical decisions at exactly the same times.

True simulations are often termed "systemic" or "closed" models because they are designed to have little or no player interaction during a run of the model. The creation of the scenario will drive the model and the outcomes can be compared as a function of the input parameters from the scenario. This can make the comparison between the impact of two weapons systems more robust than just comparisons of the physical attributes such as rate of fire, maximum, range, etc. Additionally, a well designed systemic model can be run interactively, although this changes its purpose from repeatable experimentation to exploration. At any point, a decision can be turned over to an operator rather than having the model use its own decision logic.

Combat is a human endeavor and the ability to model it is severely hampered by the need to create methodologies to make decisions. Human beings use methodologies also, but they are not likely to consistently follow them in exactly the same manner time after time. Unless there is a mechanism to vary the decision logic, a computer will make the same decision, given identical inputs. This incongruity makes the creation of systemic models a significant undertaking. The integration of stochastic events and systemic decision making is the challenge that faces today's combat models. Both issues have been dealt with separately, but until the creation of JWAEP, there were no models that completely attempted both.

C. JWAEP MODEL

1. Model Description

The JWAEP model is a systemic, aggregated (low-resolution), stochastic combat model which uses a network representation of the terrain and a square grid for airspace, and can be operated in an interactive mode. The use of the network structure helped distance JWAEP from the realm of "piston" representation of combat common in older models. During the Cold War, a full scale theater battle with the Soviet Army was envisioned in Europe. Modelers anticipated a large, linear battle with clearly defined fronts and boundaries. The advent of maneuver warfare brought with it a shift away from a linear battlefield to a more fluid and dynamic, non-linear environment. JWAEP's network structure makes it fully capable of modeling the complexities of non-linear combat.

One of the principal advancements made by JWAEP is the incorporation of uncertainty into the decision algorithms (i.e., using perceptions of the enemy locations and actions to drive decisions rather than ground truth) in addition to applying variability to outcomes. Much like real combat, these perceptions of the enemy are developed from

information collected by sensors in the model, which must then be evaluated and converted to what is traditionally deemed “intelligence”.

2. Methodology

Using Bayesian probability updates, the model computes perceived enemy strength in a particular area (either on a node or an arc). Each time a sensor passes over a particular area, it “sees” a specific number of enemy armored or motorized vehicles. Given the probability of detection (P_d) for the specific sensor, the model can estimate not only the actual number of vehicles in the area, but also the estimate's own variability. The information from the next pass by any sensor can be combined with prior sensor passes to compute the most accurate estimate possible.

From this estimate of individual elements, a probability distribution of force compositions can be determined. By comparing the estimate number of individual equipment types to templates of enemy units, the model computes the likelihood that, for example, an armor brigade is on node 26 given that 150 tanks are estimated to be present from the sensor readings. This single likelihood is then divided by the sum of all possible force combination likelihoods to compute the probability that there is an armor brigade on node 26. Clearly, it is important for an operational decision maker to have as accurate an idea as possible of the size and type of a unit on a node even if it is not possible to identify the exact unit.

The JWAEP model currently uses these force composition probability densities on the nodes and arcs to generate probability estimates for pre-determined enemy COA's. The COA's are basically a description of the method by which the enemy is attacking the defender. Each COA will outline the numbers and types of forces present on principal avenues of approach. By comparing the probabilities of certain unit types on a designated avenue of approach, each COA can be assigned its own probability using similar likelihood

procedures as discussed above. For a more in-depth discussion of the Bayesian updates, likelihood estimates, and COA probability determination in JWAEP, consult the thesis by Schmidt [Ref. 9].

Some of the significant advances in JWAEP have additional advantages over previous combat models. The use of probability vectors to represent the size and types of units present allows the model to realistically account for the impact of attrition on the perceptions of enemy unit strength. If an enemy division has been heavily attrited, it may appear to be a brigade sized unit, regardless of the command and control structures. Instead of being overly concerned with the issue of unit identification, the model accounts only for assets that pose a threat to friendly forces. This allows the decision maker to better allocate his forces for combat.

The explicit representation of uncertainty in the form of variability of asset estimates is also a significant advance in combat modeling. Uncertainty in combat is clearly not an all-or-nothing venture. There will usually be a sense of the situation with some level of confidence. By incorporating the estimates of variability in the asset counts, the model's algorithms can represent the ability to make decisions under uncertainty using realistic representations of the intelligence normally presented to the maneuver commander. The only significant difference is that JWAEP references units by their location and then assigns probabilities concerning their type and size. In real combat, the focus tends to be on specific units and the uncertainty in determining their location and strength.

D. ADDITIONAL TERMS

The major conceptual addition to the JWAEP model for this thesis is the incorporation of four value categories used to describe the significance a unit, facility, or location may have in the context of a theater level conflict. These four categories are military, political, economic, and social.

1. Military

Military value is the importance a unit, infrastructure, or area can have to the military leadership of a nation or other organization, such as a faction, clan, etc. It encompasses an ability to locate, move toward, engage, and attrite enemy forces or an ability to support, supply, sustain, and protect friendly forces. In a theater level conflict, the destruction of the enemy's military power is the surest method of defeat.

2. Political

Political value is the importance a unit, infrastructure, or area can have to the political leadership of a nation or other organization, such as a faction, clan, etc. It encompasses those elements that can affect the government's ability to control the nation or the military, as well as the reputation of the government both to its own populace and to the world at large. In a theater level conflict, attacks on the enemy's policy makers can bring about a rapid, perhaps only tenuous, end to hostilities.

3. Economic

Economic value is the importance a unit, infrastructure, or area can have to the economy of a nation or other organization, such as a faction, clan, etc. It encompasses those elements that maintain the smooth flow of goods and trade as well as their individual financial importance. In a theater level conflict, the destruction of the enemy's economic industry can create long term impact on the country's ability to function properly in an economic sense as well as prohibit them from waging war from a financial aspect.

4. Social

Social value is the importance a unit, infrastructure, or area can have on the population of the nation or other organization, such as a faction, clan, etc. It encompasses those elements that affect popular opinion, especially toward their nation, its government and military. In a theater level conflict, the targeting of socially important entities can destroy the popular support for the war or could possibly strengthen it.

III. METHODOLOGY

JWAEP must select and prioritize possible operational objectives in order to issue unit orders when operating in the systemic mode. The physical location of the target area and its relation to friendly forces will partly determine if a forced entry mission is feasible for that target area. Once feasible target areas have been selected, they must be ranked in order of importance or preference.

A target area's preference can be measured in terms of its value to the enemy and its significance in the overall friendly campaign strategy. If a target area is important to the enemy, then it follows that it is desirable for friendly forces to occupy, control, or destroy it. Defining this importance or "value", however, poses great difficulty and will be discussed in more detail. For a theater level combat model, value should consider not just the military capability present but also any political, economic, or social importance at the strategic level.

The significance of a target area with regard to the campaign strategy can depend on many factors. The distance from the target area to the strategic objective can serve as an initial measure of its importance in the campaign. The extent to which the target area supports the perceived enemy course of action (COA) could be another.

To prioritize each target area, its overall value and strategic importance should be weighed against the enemy's intent to defend against such occupation, control, or destruction. A crucial power plant would have inherent value to the enemy; accordingly, there would be enemy assets dedicated to defend it. A large enemy unit certainly is a valuable target, but its own defenses make it difficult to engage with minimal risk. By comparing the total value of a target area to its defensive capability, a relative measure of preference can be determined for prioritization.

To incorporate an objective selection algorithm in JWAEP, there are specific modifications that should be made to the data structures of the input files. Once the database contains all necessary information, the feasibility and priority algorithms can nominate and rank potential objectives.

A. SCENARIO DATABASE CREATION

The battlefield environment and force information are among the principal elements of a combat model's scenario. The battlefield environment will contain terrain and geographic information while the force information will contain the initial location, size, organization, and equipment lists for all of the units. When modeling a specific region, the battlefield environment information can be obtained from maps and charts for the theater, while the force representation will come from current intelligence estimates which include a consideration of doctrinal employment of the forces involved. If analysis of a specific region or enemy is not necessary, a notional database could be constructed.

To compute a measure of value for each target area, the geographic components which define the target area and any units or structures present must be examined. In JWAEP, those geographic components are the arcs and nodes of the network. Although there are units already present in the model, additional data structures must be added which represent the infrastructure targets which are commonly targeted in a theater level conflict.

1. Network Modifications

a. Center of Gravity

The ability to designate a key location or unit as a strategic objective does not exist in JWAEP. In a theater level conflict the center of gravity for the campaign is likely to be the enemy's capital city or seat of political power. This information could be added to the network during scenario creation so it can be used during the execution of the

model and the objective selection algorithm. The determination of a single strategic objective is necessary to focus the direction of the missions assigned to units during the battle and to assist in selecting intermediate objectives throughout the campaign.

b. Beach Terrain

The incorporation of amphibious forces into JWAEP was initially developed in a Master's thesis by LT Mike Fulkerson, USN in September, 1994 [Ref. 10]. Essentially, the amphibious forces are represented as ground forces located on "ship" equipment types on "sea" nodes that can be detected by the enemy so as to affect COA perception. Currently the movement from ship to shore does not include a specific beach area or node; there are only arcs that connect sea nodes to ground nodes. A terrain type that represents the transition point from water to land must be added to represent those sites which allow for a surface offload of amphibious forces. It can also be used to determine the distance that the assault force can maneuver inland either by foot or by vehicle. The addition of the beach terrain type is a starting point for further refinement of the model to account for the effect of mines both in the surf zone and on the beach itself, in addition to the standard land and water mines. Mine warfare significantly impacts littoral operations and must be included in future versions of JWAEP.

c. Inherent Value

The network should also include an interpretation of the importance of the nodes and arcs themselves. Each element can possess military, political, economic, and social value to the enemy. A specific location on the battlefield may possess inherent tactical value to a maneuver commander. The assignment of this value could be tied to the Commander's Preparation of the Battlefield (CPB, also known as Intelligence Preparation of the Battlefield or IPB). The CPB process helps the maneuver commander determine

mobility corridors and specific areas of interest in his operation area. If an arc, for example, is considered a high speed avenue of approach (e.g., an open valley), its control would have more importance than an area designated "slow-go" or "no-go" (e.g., a densely vegetated river valley). Currently all nodes and arcs have terrain types assigned but they are used only for unit movement rate calculations. A flat terrain type may possess tactical or even operational value because it facilitates movement. High ground overlooking a large area may have poor trafficability yet could have tactical importance as it provides excellent observation and defensibility.

There may be political, economic, and social value associated with a target area even if there are no significant infrastructures or military units present. The Nuremberg Parade Field was bombed by the Allies in World War II for the sole purpose of destroying Hitler's prized marching grounds. Surely it had little military importance to the German Army at that point in the war, but the political impact was considered large enough to expend ordnance and risk lives. This attempted psychological blow to an enemy's military leader resurfaced in the Persian Gulf War when Coalition air forces proposed bombing the statue of Saddam Hussein. Although it was not actually done, the intent was the same [Ref. 11: p.245]. Another example is an agrarian community; it may have substantial economic and social impact while having little military or political value.

The operational commander should have final determination of a target area's importance. Some form of this information should exist in the CINC's campaign plans and since these plans are updated on a regular basis, it seems best to assign the importance of nodes and arcs during the scenario construction phase. Each decision maker will have a unique interpretation of the meanings of the value parameters as well as his own method for assigning actual values to specific elements of the network. The algorithm does not constrain the user to any range of values during the creation of the scenario. While it is suggested that a scale of 0 to 100 be used for the four value determinations, the use of

fractions of the summed values eliminates the need for fixed ranges of values. Two absolute requirements must be met, however. The first is the need for consistent value assignment across all network elements and within each value category. For example, an infrastructure target with political score of 40 should be twice as valuable as one with a score of 20. The second is a minimum amount of correlation between value parameters for a given node, target, or unit. This means that the values assigned should not include secondary effects (e.g., if a node has military value, then it has political value because the policy makers understand its military importance). The values should be as independent of each other as possible. The decision maker should assign them considering only each specific value by itself.

In future work, it may be possible to suggest military values for elements of the network during the database construction. For nodes, the key considerations could include the size, terrain type and number of connected arcs (or degree). For arcs, they could include width, terrain type, and size of adjacent nodes. The crucial aspect to remember is that these assigned values should not be influenced by any factors other than the network elements' own characteristics. They should not be dependent on infrastructure or perceived enemy forces present. These influences will be accounted for separately.

2. Infrastructure Targets

Currently, the only possible targets in JWAEP are military units. On any node or arc, there may be static infrastructure present which can be of importance to the enemy's ability to conduct the campaign. The same values (military, political, economic, and social) can again be used to describe these static targets. Clearly, an ammunition plant would possess significant military value to the enemy. The destruction of the plant, or control of the area surrounding it, prohibits its use by the enemy. In some cases, certain infrastructures may be advantageous to occupy for future use by the friendly forces and

would not be targeted for destruction or neutralization by destructive means. The author experienced an example of precisely this concern during Operation Desert Storm. The water desalinization plants in some locations were intentionally not bombed so they could be later used by Coalition Forces, if necessary. In this case, the water purification plants had significant military value to both sides for logistical reasons. This situation lends itself to occupation of the objective by forced entry missions because attack by air assets alone may have undesired effects.

The intelligence assessment of an enemy's infrastructure is currently part of theater level campaign planning in all of the Unified Commands. The static nature of factories and other facilities makes the estimate of their value somewhat easier than for non-static elements. Comparisons in size, and therefore significance, can assist in assigning realistic values to particular targets such as power plants or telecommunication centers. Although it can be assumed that enough information will exist prior to and during hostilities to identify them explicitly, it may be necessary to create infrastructure target types specifically for targeting purposes. The addition of the actual target to the network is similar to adding an additional node or arc, since the infrastructure is not mobile.

The parameter assignments for the four value types are made during the creation of the scenario. The values must be on the same scale as that of the nodes and arcs (0-100) so that they are directly, numerically comparable. For example, a railroad yard (infrastructure) with a military value of 45 should be three times more important than a mountain pass (arc) with a military value of 15. The process can rely on both intelligence estimates and the operational commander's input.

The assignment of value by the operational commander is sufficient to use as a starting point for the initial construction of this objective selection algorithm. As mentioned previously, further investigation can be done in an attempt to incorporate the dynamic

assignment of these parameters into JWAEP, if desired. For the purpose of this thesis, the values will be predetermined and input during the scenario generation.

3. Initial Unit Information

a. Military value

The JWAEP model includes the doctrinal tables of organization and equipment (TO&E) for unit types of both forces in the conflict. At the outset of the model's execution, the actual numbers of equipment and personnel are randomly modified to represent the shortfalls or excesses commonly seen in military units. These deviations will result in actual unit strength changes that would not be apparent to the planning entities of the opponents. Included in the TO&E are the individual weapon systems firepower scores. The basic service rifle is assigned a numerical value of 1.0 and all other weapon scores are determined relative to this. The TO&E is currently used to compute the perception probabilities for units on a node and will be incorporated into the determination of both value and defensibility.

The incorporation of additional aspects of a unit's combat effectiveness is currently under development in JWAEP. The initial proposal of aggregated strength variables included categories of Command, Control, Communications and Intelligence (C^3I), Attrition, and Logistics [Ref. 12]. Further refinements under development include additional transport parameters under the Logistics category [Ref. 13] and a new Mobility category which will be concerned with a unit's combat engineer assets [Ref. 14].

Some of these capability parameters will be directly tied to measurable quantities in JWAEP. They will be determined from specific asset counts, much like the calculation of the firepower score. For example, a unit that possesses significant motor transport assets will be more capable of sustaining itself logistically, and its logistic strength values should reflect this. Similarly, a unit with combat engineering equipment

and personnel attached will have higher mobility and counter-mobility strength than one without these assets.

One proposed strength variable, Command and Control (C^2), presents greater difficulty in both assignment and subsequent interpretation. C^2 strength is not the result of reliable communication equipment or doctrine alone. It is closely tied to the internal operating procedures of the unit and the individuals in leadership positions. Leadership, like training and morale, can have a tremendous impact on a unit's effectiveness in combat. While these measures are less quantifiable, they should be incorporated into a combat model, if possible. Intelligence estimates and combat history can provide some insight into the determination of the parameters and they could then be used to enhance or degrade a unit's performance in combat. Again, the need for consistent value assignment is imperative given the importance these factors have in real combat.

The unit strength variables pose a considerable challenge to JWAEP's use of perception based representation of enemy units. It currently does not allow one side to "know" or identify specific units from the other. The perception information concerning force composition and size classifies units only by the number and type. Additionally, it does not provide simply a single unit type with some measure of accuracy (e.g., " there is an armor brigade within 500m of grid 123456" or "there is a 75% chance that there is an armor brigade located at grid 123456"). Instead, it presents all of the possibilities of the combinations of units which could be present on a specific node or arc and assigns a probability to each. As it stands now, the perception database for each side during the conflict reaches a substantial size considering only unit types. The aggregation of units to the brigade level has profound impact on the inferences that can be made about the type of unit detected by friendly sensors. Brigades are traditionally composed of many different types of equipment and this will hinder the ability to exactly classify unit types, much less specifically identify individual units. To generate and keep track of all possible

combinations of specific units, as well as computing probabilities for each, would clearly be computationally and numerically overwhelming. Accordingly, the assignment of military value will, at present, be restricted to unit types based on generic firepower scores only.

b. Non-military Value

While it is clear that an enemy unit will have military value, it may also possess some of the other three types of value. The Republican Guard of the Iraqi Army, for example, was heavily targeted during the Persian Gulf War. While the principal reasons for this were their assignment as Iraq's strategic reserve, their size, and their combat reputation, there was an additional benefit gained by their engagement. As Saddam Hussein's national security force, the Republican Guard was highly regarded throughout Iraq and the damage caused by Coalition bombing had a decided political impact. His mainstay force was getting destroyed before engaging in actual combat. The additional facets of a military unit's non-military value provide grounds to incorporate additional political, social, and economic values for each units.

Again the issue of unit specificity in JWAEP poses an obstacle. The political, economic, and social values, however, can be assigned by the operational commander for different unit types and sizes. For example, a generic armored division would seemingly have more political value than a light infantry brigade. There is the possibility that light units may be considered differently than heavy units by the people of the nation. For example, a relatively small insurrection or guerrilla force may have high social value without much political, economic, or military value.

Tied to the equipment table for a unit type, the individual cost for each equipment type could serve as a preliminary measure for a unit type's economic value. A technological improvement in a weapon system may improve the individual weapon score

and could dramatically increase its price. The difficulty in replacing these newer items can increase their desire to be destroyed by the opposition. If a well-equipped, elite unit is one of only a few of its kind in existence and it is somehow engaged and destroyed by the enemy, then the result is a not only a military success, but potentially a political, economic, *and* social one.

The difficulty in assigning non-military values to combat units stems from the interpretation of psychology on a grand scale. The politicians must perceive a value of a tank division in addition to recognizing its inherent military value. The economy must feel the impact of the destruction of a high-tech fighter squadron. The operational commander needs to anticipate these factors when generating the parameter values during the creation of his campaign plan.

This thesis will not further investigate the levels and meanings of these value parameters for units or other elements in the model. It is imperative to recognize both their importance and the difficulty of their determination. For now, it is sufficient to have the operational decision maker provide his input to the model as the starting point.

B. INITIAL FEASIBILITY BY MISSION TYPE

The principal constraint in limiting which target areas are candidates for an operational forced entry assault is the travel distance required. An aggressive insertion of forces into a potentially hostile area demands a viable extraction or withdrawal plan in the event that neither successful consolidation on the objective nor a link-up with friendly forces is possible. The limitations of the transport equipment available will be the principal constraints. These maximum distances for each mission can serve as an initial filter of all the nodes occupied by the enemy in the model. Using a straight-line distance comparison, potential target areas can be screened for further examination.

1. Amphibious Assault

For an amphibious surface assault to an inland objective, the primary concern will be the range from the ship to the target area, through the beach. The force must not only be able to reach the objective, but also retain the ability to withdraw if the mission's success becomes unattainable. The size of the assault force will determine how much of an offensive, inland push can be achieved while maintaining the requisite defensive security of the support lines from the beach to the objective. The maximum distance will primarily be a function of the ground transport assets' operating ranges. Further analysis of a target area's feasibility is possible using algorithms already present in JWAEP. A modified Dykstra's algorithm using both distance and perceived enemy locations selects routes for ground maneuver [Ref. 9: p. 33]. It can be used to determine the route along the nodes and arcs of the network to objectives which are within the maximum range limitations for the amphibious assault. There may be a substantial difference between the straight-line distance between two nodes and the actual distance required to travel between them in the network as shown on Figure 2. For the amphibious mission, the range used is the distance from the target area to any beach node.

2. Airborne and Air Mobile Assault

The airborne and air mobile assaults have increased risk because they do not secure a surface route as they move to the objective. The nature of an airdrop or helicopter insertion requires an aircraft extraction or a link-up with ground forces. If the surface route to friendly lines is both lightly defended and short enough for the assault force to execute a ground extraction by themselves, then the operational commander would probably not choose an airborne or air mobile forced entry mission with its inherent risk over a basic ground maneuver mission.

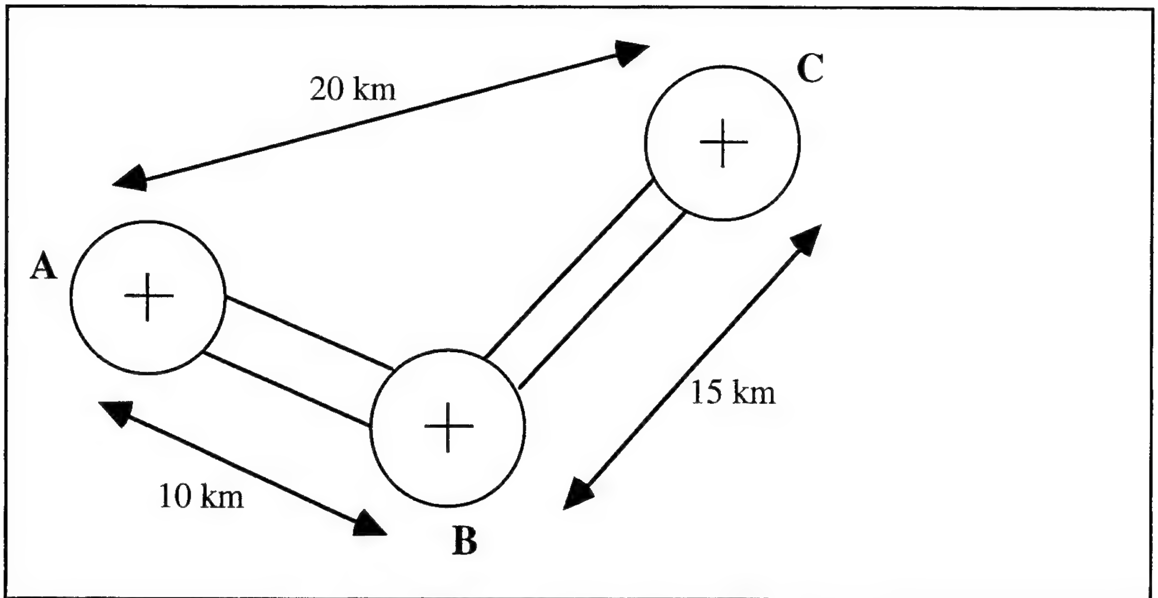

Figure 2. Distances Between Two Nodes

The maximum distance is determined by the helicopter transports' operating ranges. The range is calculated from the target area to any node not occupied by enemy forces capable of supporting the staging and refueling of the helicopter assets. This allows for the use of a forward arming and refueling point (FARP) in the execution of the mission.

An additional network distance comparison for the airborne and air mobile assaults is not necessary because, in reality, the aircraft can fly the straight-line path if necessary. Although JWAEP uses an air grid where the movement is between the centers of the grids, this additional constraint would not be present on the battlefield.

The primary concern at this step is the distance feasibility determination of each target area, not the specific route to be traveled. The purpose of these screening steps is to minimize the number of nodes for which the calculation-intensive value and defensibility determinations are made.

C. VALUE PARAMETER

1. Military Value

The military value of a particular unit should reflect its combat power and will primarily depend on its size and composition. The operational decision maker will not have exact counts of assets for specific units; instead, he will have a situation map with intelligence estimates of enemy unit types. JWAEP contains this information in the perception probability array for each node. A generic firepower score for each unit type can be computed using the TO&E equipment counts and each individual equipment's firepower score.

$$\text{GFP}_i = \sum_{\forall j} \text{w}_j \, \text{x}_{ij} \tag{1}$$

where

GFP_i = generic firepower score for unit type i
w_j = firepower score for weapon type j
x_{ij} = number of weapon type j in unit type i

Throughout this thesis, the indices used are defined as follows:

- *i* - unit type, (e.g., armor brigade, mechanized infantry brigade, ranger regiment, etc.) for both sides engaged in the conflict.
- *j* - weapon type, (e.g., T-62 tank, RPK-74 machine gun, M-16 service rifle, etc.) for both sides engaged in the conflict.
- *k* - target area: a specific node or arc that can have military units and/or infrastructure present.

l - specific infrastructure (e.g., a power plant, a telecommunications center, a ammunition factory, etc.) throughout the theater.

m - mission type - amphibious or airborne/air mobile.

v - value type – military, political, economic, and social.

It is important to add that these firepower scores are to be used to provide a basis for assigning military value, not for the adjudication of combat.

The perception database allows the algorithm to determine the expected enemy unit firepower score for each target area by multiplying the probability of each unit composition by its appropriate generic firepower score.

$$E[FP_k] = \sum_{\forall i} p_{i,k} \, GFP_i . \qquad (2)$$

where

$E[FP_k]$ = expected total firepower in target area k
$p_{i,k}$ = perception probability of unit type i in target area k
GFP_i = generic firepower score for unit type i (from Eqn. 1)

Since hundreds of weapons are present in a brigade sized unit, these expected target area firepower scores will be substantially larger than the military value of the target area and any infrastructure targets, as well as the other value parameters (political, economic, and social) of the target area. To overcome this order of magnitude problem, each target area's unit firepower score is normalized by the sum of all nominated target area unit firepower scores.

$$\text{NormFP}_k = \frac{E[\text{FP}_k]}{\sum_{\forall k} E[\text{FP}_k]} \tag{3}$$

The target area's inherent military value and all of its infrastructure's military value can be directly added to form a measure of static military value.

$$\text{StatMil}_k = \text{TgtAreaMil}_k + \sum_{\forall l} \text{InfraTgtMil}_{k,l} \tag{4}$$

where

StatMil_k = total static military value in target area k
TgtAreaMil_k = inherent military value of target area k
$\text{InfraTgtMil}_{k,l}$ = miltary value of infrastructure l in target area k

Each target area's static military value is also normalized by dividing by the sum of all the target areas' static military value.

$$\text{NormStatMil}_k = \frac{\text{StatMil}_k}{\sum_{\forall k} \text{StatMil}_k} \tag{5}$$

A target area's overall military value is a combination of both the expected firepower score and the static military value. Since both values have been normalized, a weighted sum can be used to provide a single measure.

$$\text{NormCombMil}_k = \alpha_1 (\text{NormFP}_k) + \alpha_2 (\text{NormStatMil}_k) \tag{6}$$

where

α_1 = weight given to firepower estimate

α_2 = weight given to infrastructure and area inherent military value

and

$$\alpha_1 + \alpha_2 = 1.0$$

The relationship between α_1 and α_2 represents the operational commander's relative importance of the target area's total unit firepower scores to its fixed military value. If, for example, he felt that military units are three times as important as infrastructure and area inherent values, the assignments for α_1 and α_2 would be 0.75 and 0.25, respectively. Hence, this could also serve to represent the difference between campaign goals of destroying the enemy's military and defeating the entire nation.

2. Non-Military Value

The non-military values are added in the same fashion as the military value. Despite not having the numerical magnitude problem for military units' values because the range for all the non-military values is fixed, there are perception probabilities to address. Since each unit type has different political, economic, and social importance, an expected value for each can be computed in a similar manner as the expected firepower score. The following equations specifically outline the procedure for the computation of the political value of a target area. The process is identical for both the economic and social values, as well.

$$E[\text{PolVal}_k] = \sum_{\forall i} p_{i,k}\ \text{PolVal}_i . \qquad (7)$$

where

$E[PolVal_k]$ = expected total military unit political value in target area k

$p_{i,k}$ = perception probability of unit type i in target area k

$PolVal_i$ = generic political value for unit type i

The expected unit political value of each target can also be normalized by the total unit political value in all the nominated target areas.

$$NormPolVal_k = \frac{E[PolVal_k]}{\sum_{\forall k} E[PolVal_k]} \tag{8}$$

The static political value of the target area and the infrastructure present can be added together without any modification because they should be on a consistent, comparable scale.

$$StatPol_k = TgtAreaPol_k + \sum_{\forall l} InfraTgtPol_{k,l} \tag{9}$$

where

$StatPol_j$ = total static political value in target area j

$TgtAreaPol_j$ = inherent political value of target area j

$InfraTgtPol_{j,k}$ = political value of infrastructure k in target area j

Each target area's static political value is normalized by dividing by the sum of all the target area's static political value.

$$\text{NormStatPol}_k = \frac{\text{StatPol}_k}{\sum_{\forall k} \text{StatPol}_k} \qquad (10)$$

A target area's overall political value is a combination of both the expected military unit political value and the static political value. Since both values have already been normalized, another weighted sum can be used to provide a single measure of political value.

$$\text{NormCombPol}_k = \alpha_1 \, (\text{NormPolVal}_k) + \alpha_2 \, (\text{NormStatPol}_k) \qquad (11)$$

where

α_1 = weight given to estimate of military unit political value
α_2 = weight given to infrastructure and inherent area political value

and

$$\alpha_1 + \alpha_2 = 1.0$$

The coefficients, α_1 and α_2, are the same weights used before in the military value computation. For now, the operational commander should be consistent in the relative importance of military units to the infrastructure and target area, regardless of the specific value being measured. Future enhancements of the algorithm might include separate pairs of importance weights (α_1, α_2) for each of the four value types. The relative weights of the four value parameters will be addressed later.

Each of the three non-military value calculations outlined above will produce a combined measure of the fraction of that value over all the possible target areas like the

military value calculations. These four combined values can be further reduced into a single measure which represents the fraction of total value of a given target area compared to all the other target areas.

$$\text{NormTotalVal}_k = \beta_1 (\text{NormCombMil}_k) + \beta_2 (\text{NormCombPol}_k) + \beta_3 (\text{NormCombEcon}_k) + \beta_4 (\text{NormCombSoc}_k) \qquad (12)$$

where

$$\sum_{\forall v} \beta_v = 1.0$$

and

$$v = \text{Mil, Pol, Econ, or Soc}$$

The β coefficients represent the relative importance that the operational decision maker places on each of the four types of value. If he feels that military value is twice as important as each of the other values (equally weighted), then the coefficients would be 0.4, 0.2, 0.2, and 0.2, respectively. This further allows the algorithm to focus on the priorities of the operational commander. These coefficients need not be constant throughout the entire execution of the model. As the campaign moves from one phase to another, these priorities may change to reflect the different goals of each phase.

The final result is that fraction of all the perceived enemy assets, infrastructure, and inherent value located in the specific target area. Clearly, the higher the final number is compared to other target areas, the more appealing it is to the operational commander.

D. STRATEGIC IMPORTANCE PARAMETER

In a major regional contingency (MRC), there is likely to be a defensive phase where U.S. forces arrive and consolidate prior to attempting to go on the offensive to return the country to the status quo. Once the friendly forces begin an offensive campaign, the strategic objective becomes the point toward which they will move, either directly or indirectly. There will be many factors which determine the importance of a target area in the campaign plan. They can include the effect of the target area on the ability to conduct further offensive operations, the impact on the probable course of action (COA) being executed, and the overall impact on the conflict. For the purpose of this thesis, the principal consideration will be the distance of the target area to the strategic center of gravity. A target area in close proximity to the strategic objective is assumed to have more appeal in a operational forced entry than one which is very far away from it. Of course, it is possible that a more appealing target area may have more enemy located there, since it likely that the enemy center of gravity would be well defended.

At the beginning of every operational maneuver planning cycle in JWAEP, a basic calculation of the distance from the strategic objective to the closest friendly unit is calculated. For each target area nominated for evaluation, the distance to the strategic objective is also determined as shown in Figure 3.

The ratio of the target area's distance to the strategic objective ($\mathrm{StratDist}_k$) and the distance between the closest friendly ground unit and the strategic objective (MaxStratDist) represents the relative improvement gained in moving forces closer to the strategic objective.

$$\mathrm{StratImp}_k = \frac{\mathrm{DistStrat}_k}{\mathrm{MaxDistStrat}} \tag{13}$$

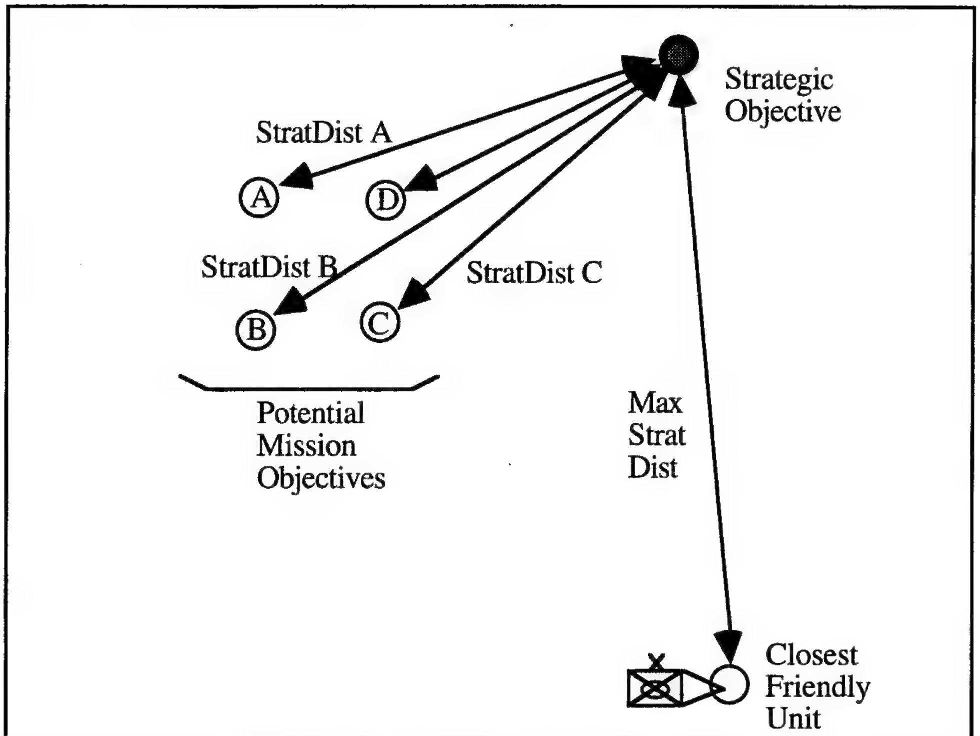

Figure 3. Target Area Locations

If a target area is more distance from the center of gravity than the distance from the closest friendly unit, the ratios are then determined using this new maximum distance to friendly forces. Even though the value of the strategic importance parameter is restricted between 0.0 and 1.0, the implication is not the same as for previous parameters. The ratio is not based on the sum of the distances from all target areas so the fractions will not sum to 1.0. However, comparisons between different target areas can still be made because a common maximum value is used.

Each target area's distance parameter has a negative correlation with its preference. Seizing an objective that is close to the friendly forces does not gain much strategic advantage; however, the normalized value from the distance calculation is close to 1.0. Similarly, the strategic objective itself would have a distance value of 0.0. Because the maximum value is 1.0, the result can be subtracted from 1.0 to give a more traditional

meaning to the results. This way, a 1.0 is given to the strategic objective itself, and a number close to 0.0 would appear for target areas near friendly forces.

E. ENEMY DEFENSE PARAMETER

If a target area has substantial inherent value and significant infrastructure value to the enemy, it is reasonable to assume that they may take steps to defend it by positioning combat forces in the vicinity. Only military units or their equipment are capable of attriting friendly forces, therefore the estimates of the defensive capability in a target area will be solely a function of the perceived enemy forces located there. The method used to determine this defensive capability is somewhat different than that used to determine the military value of the target area. The perception database presents the operational commander with a distribution of possible units in the target area, but the underlying asset counts for each target area provide a better basis for the calculations. The defensibility parameter relies solely on equipment counts, so no additional parameters (i.e., the unit type's political, economic, or social value) need to be considered.

Three additional factors must be considered for the estimate of enemy defensibility. The first concerns the dynamic nature of enemy units in a combat zone. Between the time a target is nominated until the mission orders are sent and the execution begins, enemy forces may move to new locations. The second concerns the actual weapons that may be used by the enemy to defend against the assault force. The weapon systems that severely threaten an airborne or air mobile forced entry mission may not have the same impact on a surface amphibious assault. The third factor is the uncertainty in the underlying asset counts, themselves.

1. Enemy Movement

The possibility that additional enemy units may move into the target area can be predicted somewhat by an operational decision maker if accurate and timely intelligence reports allow him some ability to track their movement. However, the single snapshot of enemy unit perception probabilities used to compute military value and defensibility does not enable the algorithm to predict movement between the planning cycles. Therefore, a logical method to account for this potential build-up of enemy combat power in the target area is to include *all* enemy units within a certain distance of the target area. While all of the units in the vicinity will probably not move to that single area, they do have the potential to threaten the success of the mission if they are indeed present at the time of execution or can quickly move to engage the assault force once the mission begins. Enemy forces should be expected to attack as quickly as possible, once aware of the friendly mission, in order to engage the assault force before it can fully consolidate on the objective. By considering all units within a certain range of the objective, a commander can obtain a conservative estimate for the relative density of enemy units that may be encountered near a specific target area.

2. Weapons Threat To Specific Mission Types

The weapons possessed by the perceived units in and around the target area are included in the defensibility parameter for that target area only if they pose a direct threat to the assault force during the assault. This restriction does not change the military value calculations described earlier, since the firepower scores represent general military value to the enemy forces and are not situation dependent. The use of all of their assets in a specific defensive scenario, however, may not be effective; not every weapon type should necessarily contribute to the defensibility parameter. For example, the presence of an air defense artillery battery would have more impact on the estimate of defensibility for an

airmobile assault than for a surface amphibious assault. The battery would still have military value to both missions but would present serious threat only to the airmobile assault force. Although the air defense battery could inflict damage on aircraft supporting a surface amphibious assault and may slow its progress, it would probably not attrite the assault force significantly. It is important to clarify that the defensibility factor will include only those unit and equipment types which can pose a direct threat to the force attempting to seize the objective; it is not intended to include all combat power.

3. Asset Count Uncertainty

In addition to the intentions of the enemy, a commander must consider the accuracy of the intelligence estimate of the distribution of enemy forces. The inherent uncertainty of information on the battlefield leads to the use of more conservative estimates of the defenses present. If there is greater variability in the estimate of enemy combat power in a particular target area, there should a relative decrease in the overall desirability of the target area. By incorporating the variability of the assets counts computed by JWAEP with each sensor update, this uncertainty can be taken into consideration in prioritizing the target areas.

4. Computation Of Defensibility

A defensibility asset count for each target area is computed by adding together all the asset counts for the target areas that are within range as described previously. The asset counts are estimated from the sensor returns for each target area. If the number of assets sensed, S, is considered to be binomially distributed with a probability of detection, p_d; then the estimated number of assets at the target, $\hat{N}$, and the estimated variance of that estimated number are given as:

$$\hat{N} = \frac{S}{p_d} \quad \text{and} \quad \hat{\mathrm{V}}\mathrm{ar}(\hat{N}) = \hat{N}\left(\frac{1 - p_d}{p_d}\right) \tag{14,15}$$

If there have been enough sensor passes, the Central Limit Theorem justifies the assumption that the accumulated estimate, $\hat{N}$, is normally distributed. It is then possible to compute a (100-α)% upper confidence limit for the number of assets in and around the target area.

This technique allows the decision maker to take a more conservative approach to the estimate of the defenses present by using a (100 - α) percentile of the distribution of $\hat{N}$ rather than using the expected values.

$$\mathrm{Def}_{k,m} = \sum_{\forall k'} \sum_{\forall j} d_{j,m}\, \mathrm{w}_j \left(\hat{N}_{j,k'} + z_{(100-\alpha)\%}\sqrt{\hat{\mathrm{V}}\mathrm{ar}(\hat{N}_{j,k'})}\right) \tag{16}$$

where

$\mathrm{Def}_{k,m}$ = defensibility parameter for target area k and mission m

$\mathrm{d}_{j,m} = \begin{cases} 1, & \text{if weapon type } j \text{ defends against mission } m \\ 0, & \text{if not} \end{cases}$

w_j = firepower score of weapon type j

k' = all nodes and arcs within the defensibility range of target area k

$\hat{\mathrm{N}}_{j,k'}$ = estimated number of weapon type j in the region k'

$\hat{\mathrm{V}}\mathrm{ar}(\hat{\mathrm{N}}_{j,k'})$ = estimated variance of $\hat{\mathrm{N}}_{j,k'}$

The defensibility parameter can also be normalized by dividing by the total defensibility for all target areas for each particular mission type.

$$\text{NormDef}_{k,m} = \frac{\text{Def}_{k,m}}{\sum_{\forall k} \text{Def}_{k,m}} \tag{17}$$

This represents the fraction of all enemy forces that can threaten a specific mission type. The higher the fraction, the greater the risk of the mission. Again, a transformation is desired to maintain the relationship between increasing parameter values and increasing desirability. Subtracting the defensibility parameter from 1.0 accomplishes this, just as it did with the strategic importance parameter.

F. RELATIVE DESIRABILITY

In order to arrive at a single value by which to determine the most preferred target area for the forced entry assault, the three parameters of value, strategic importance, and defensibility must be combined. Since all three parameters have been converted to a scale of 0.0 to 1.0 with increasing preference for each, they can be modified using basic utility equations to more realistically represent the importance of the different specific values of each parameter.

1. Utility Theory

Utility theory provides a framework from which to measure the importance of one parameter over another. It also incorporates the ability to discriminate between the importance of values or ranges of values for a given parameter. Essentially it is a mathematical tool to represent the importance of outcomes and the risks involved. A linear utility curve for a parameter would imply that each increase in the measure of interest will produce proportional increases in the utility or importance of the outcome. Traditional utility curves assign a value of 0.0 at the minimum value of the measure of interest and 1.0

at the maximum. Having transformed the parameters to [0,1] ranges, they may be fit into many classes of equations that contain the points (0,0) and (1,1). The most flexible of these are polynomials of the form:

$$U(x) = x^n \tag{18}$$

where

$U(x)$ = the utility of x

n = any number greater than 0 (not including 0)

If n is less than 1.0, the curve is convex (concave down) and represents "risk adverse" behavior. Increases in the lower ranges of x will have greater impact on the utility than those in the higher ranges. If n is greater than 1 the curve is concave up and the term "risk preferring" applies. Figure 4 shows the basic shapes of both of these types of curves.

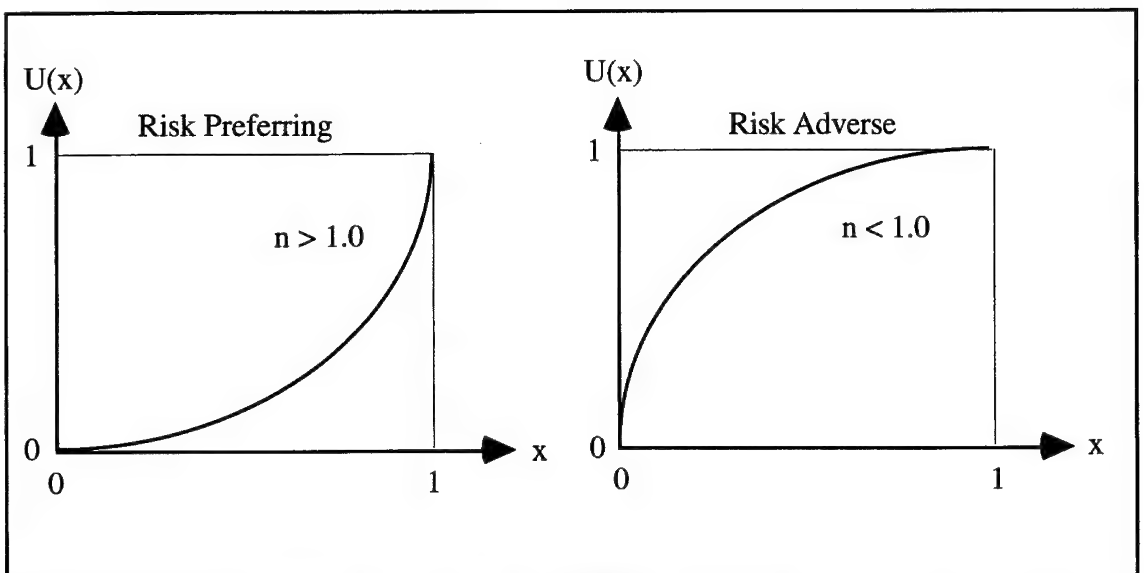

Figure 4. Basic Utility Relationships

In general, the utility equation for all of the value parameters should tend to be somewhat "risk adverse". This observation is not as obvious as it may sound. Clearly an operational decision maker will weigh the benefits of a mission against the risks; and this is captured when the utilities of the parameters are finally combined into a single parameter. For each individual parameter, however, the *utility* across the range of values requires more careful investigation. In reality, many, if not most, utility curves are neither linear nor singularly convex or concave as shown in Figure 5.

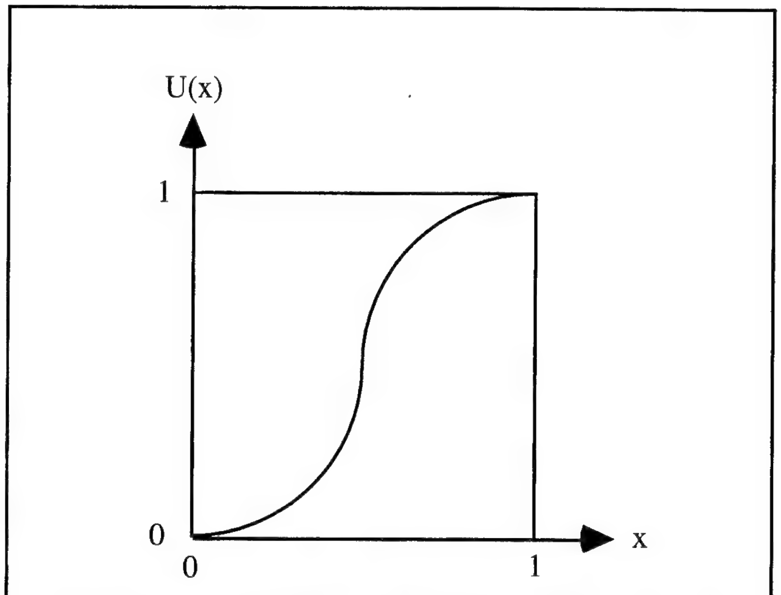

Figure 5. Realistic Utility Curve

At the lower values of the parameter, slight increases in the normalized values will produce little gain in utility. As the measure of interest moves into the middle range of its values, slight increases produce greater utility increases until a point is reached at which the increase in utility slows.

In general, the values for the three parameters will be in the range near 1/t, where t is the number of target areas being considered by the algorithm. If t is very large then the normalized values will tend to be found at the very low end of the range. Choosing a risk

adverse utility function will spread the values at the low end. The utility curves for the operational decision maker will need to be created during the scenario construction.

2. Combined Utility Equation

Once the utility for each parameter of a given target area has been computed, a weighted sum can create a final measure of utility that the target area has to the decision maker.

$$\begin{aligned} \text{Total Utility}_{k,m} &= \gamma_1 \mathrm{U}(\text{NormTotalVal}_k) + \gamma_2 \mathrm{U}(1 - \text{StratImp}_k) \\ &\quad + \gamma_3 \mathrm{U}(1 - \text{NormDef}_{k,m}) \end{aligned} \tag{19}$$

The coefficients of the utilities of each of the parameters are not required to sum to one. The parameters of strategic importance and defensibility have been subtracted from one to convert them to standard utility inputs. Since the strategic importance parameter is not a fraction of the total importance and the defensibility parameters (the complements of the fraction of the total defenses) do not add to 1.0, constraining the γ coefficients is neither necessary nor beneficial. The relative size of each of the coefficients allows the operational decision maker to represent the importance he places on each. A risk taking commander may place more emphasis on the value and strategic importance parameters, which may lead to the selection of heavily defended target areas. A more cautious commander may be more concerned with avoiding the enemy and might not achieve success in the goals of the campaign. The Total Utility for each target area/mission combination will not be constrained to values between 0.0 and 1.0 (In fact, they will range from 0.0 to the sum of the three parameter coefficients, $\gamma_1 + \gamma_2 + \gamma_3$).

Once the total utility has been computed for all eligible target areas, the one with the highest value can be designated as a forced entry mission objective. The simple

determination of highest output utility value may not be suitable to decisively choose only one, as the values may be close to one another. A threshold of advantage over the next most appealing target area may be established to single out only one objective. If the threshold is not met, then the algorithm can either designate the highest target areas within a certain range as potential objectives or it can wait until a single target area has a decided advantage.

Ultimately, the objective selection algorithm will then hand this objective off to the appropriate mission planning module that can determine the mission's overall feasibility, based on a more thorough evaluation of the perceived enemy forces in the region surrounding the objective. The planning module should estimate the attrition expected and should choose the optimal route to the objective based on both attrition and distance. Current work is being done in a Master's Thesis by Capt. George Pointon, USMC, to create this type of planning module for a heliborne amphibious assault [Ref. 15].

IV. RESULTS AND ANALYSIS

A. PURPOSE

In order to test the basic operation of the algorithm, a small network with infrastructure and military units was created so that the outputs could be easily verified. The highly subjective nature of both the predetermined value parameters (military, political, etc.) and the weights in the primary equations (α's, β's, etc.) renders an in-depth analysis difficult, to say the least. The primary goal of the analysis performed is to check the basic soundness of the algorithm. By evaluating a small set of units and infrastructure in a spreadsheet formulation of the algorithm, the decision logic output can be compared against a "common sense" solution. The spreadsheet model is available upon request from Dr. Sam Parry or LTC Mark Youngren at the Naval Postgraduate School.

B. SCENARIO

A four node network with five arcs, seven infrastructure facilities, and eight combat units serve as the baseline scenario. The network and locations of the infrastructure and the military units are shown in Figure 6. The process of screening nodes and arcs for maximum range limitations is a straightforward calculation. For this scenario, it is assumed that the 4 nodes and 1 arc are the only elements with enemy units or infrastructure located on them that were not filtered out of the initial target area screening process.

Table 1 lists the table of equipment and firepower scores for the unit types necessary for this scenario. The firepower scores in the second column are the author's estimates of the relative effectiveness of each weapon system compared to a service rifle with base value equal to 1.0. The equipment totals under each unit type (Armor Bde, BMP Bde, etc.) are slightly modified doctrinal unit equipment allocations of the former Soviet Army from an unclassified source [Ref. 16] .

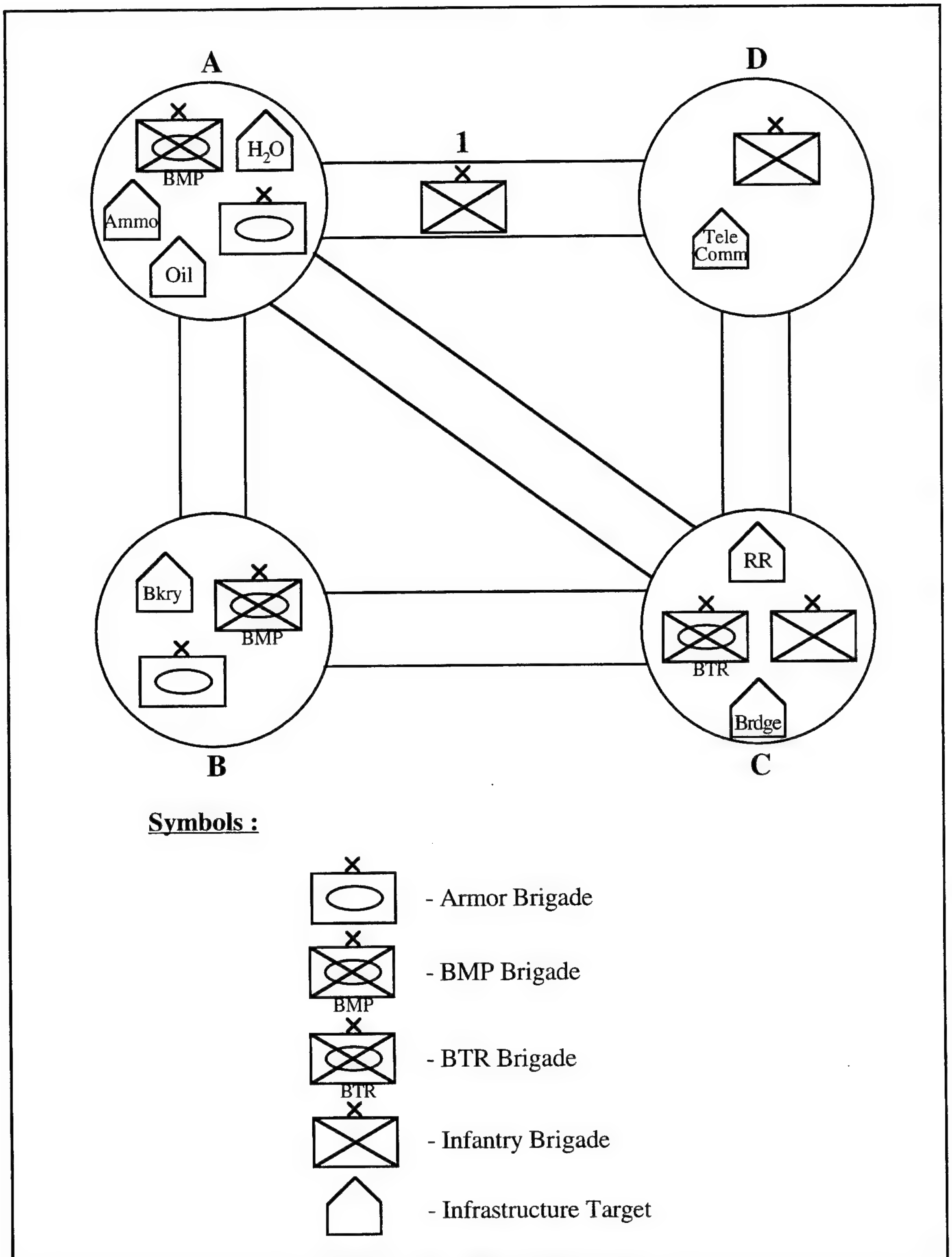

Figure 6. Test Network

TO&E	Score	Arm Bde	BMP Bde	BTR Bde	Inf Bde
T-55/62	70	94	40	40	0
BMP	30	16	133	26	0
BTR-60	20	5	6	167	0
152mm SP	50	18	0	0	0
122mm SP	35	18	0	18	0
120mm M	35	0	18	18	6
ZSU-23-4	25	4	18	18	6
SPG-9	10	0	0	6	36
RPG-16	5	36	140	146	150
SA-7	10	3	30	30	45
SA-9	25	4	4	4	0
RPK-74	5	21	201	102	111
Troops	1	1145	2225	2315	2112

Table 1. Table of Equipment

Table 2 lists the value parameter assignments for the five network elements. These would be determined by the operational decision maker or his staff at the outset of the scenario creation. Table 3 shows the infrastructure targets and their associated value parameter assignments, also done during the scenario creation.

Value	Node A	Node B	Node C	Node D	Arc 1
Military	5	5	20	10	7
Political	10	15	10	10	5
Economic	5	10	20	25	10
Social	5	5	10	10	5
Distance to					
Strategic Obj	190	245	210	130	155

Table 2. Network Value Parameters and Strategic Distances

InfraTgt	Ammo	Water	Oil	Bakery	Bridge	RR yard	TeleComm
Location	Node A	Node A	Node A	Node B	Node C	Node C	Node D
Military	90	30	40	5	25	60	20
Political	20	20	35	5	10	20	30
Economic	40	30	50	15	10	45	30
Social	10	25	15	20	10	15	30

Table 3. Infrastructure Value Parameters

C. ALGORITHM RESULTS

1. Initial Coefficient Analysis

The first series of runs of the spreadsheet model were done using coefficients at their extreme values. For each equation, fixing one of the coefficients at 1.0 and the remaining at 0.0, will generate target area preference based on only one characteristic. For example, if the only criterion for selecting the objective is the military value of the infrastructure and target area alone, then the parameters α_1, β_1, and γ_1 (in Equations 6,12, and 19) should be assigned values of 1.0 and all others should be zero. For the first set of outputs, the probability of detection is fixed at 0.8 for all target areas and linear utility (n=1.0) is used for the three parameters.

Given this situation, the output ranking (first to last) for the target areas is: Node A, Node C, Node D, Node B, and then Arc 1 (Table 4). Clearly, the three infrastructure targets on Node A (especially the ammunition factory with a military value of 90) make it more desirable than the others. There is no difference between the final utility output values and rankings for the two mission types, amphibious and airborne/air mobile, because the defensibility parameter values are not considered.

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
1	0	1	0	0	0	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.5205	0.0315	0.3312	0.0946	0.0221		
	Amphib	Rank:	1	4	2	3	5		
		Output:	0.5205	0.0315	0.3312	0.0946	0.0221		
	Airborne	Rank:	1	4	2	3	5		

Table 4. Fixed Military Value Output

Similarly, if the operational commander were only concerned with avoiding enemy defenses then both of the γ_3 coefficients (one for amphibious assault and one for airborne and air mobile assaults) would be equal to 1.0. The values for the α and β coefficients to determine value do not matter because the overall value coefficient, γ_1, is 0.0. The output ranking for this criterion is: Node D, Node C, Node B, Node A, and then Arc 1. (Table 5)

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0.5	0.5	0.25	0.25	0.25	0.25	0	0	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.7416	0.7944	0.8395	0.9182	0.7062		
	Amphib	Rank:	4	3	2	1	5		
		Output:	0.7445	0.7996	0.8373	0.9123	0.7064		
	Airborne	Rank:	4	3	2	1	5		

Table 5. Defensibility Output

Upon first inspection, Arc 1 seems to have the same defensive forces present as Node D, but the inclusion of forces within 50 km of Arc 1 brings in the units from Node A and Node D. For the same reason, Arc 1's infantry brigade is included in both Node A and Node D's defensibility totals. The two infantry brigades considered for Node D are preferred to the infantry brigade and BTR brigade at Node C. It bears noting that the values of defensibility seem misleadingly close because they have been subtracted from 1.0. The true defensibility values (for which lower scores are preferred) are in the range from 0.084 for Node D to 0.295 for Arc 1. Node C's value of 0.159 is almost twice that of Node D. It is clear there is a substantial difference. Utility functions can provide some assistance in resolving the problem of the comparison of complements and will be discussed in more detail.

There are seven additional combinations for the value-only considerations and one for strategic importance. Their results are shown in Tables 6 through 13. Each of the algorithm's rankings conforms to the intended outcomes which were designed into the structure of the scenario. For each of these initial tests, each node's simulated sensors' probability of detection, Pd, was kept constant at 0.8 and the utility equations of the value, strategic importance, and defensibility were linear with the powers in Equation 18 equal to 1.0.

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
1	0	0	1	0	0	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.4474	0.1053	0.2105	0.2105	0.0263		
	Amphib	Rank:	1	4	2	2	5		
		Output:	0.4474	0.1053	0.2105	0.2105	0.0263		
	Airborne	Rank:	1	4	2	2	5		

Table 6. Fixed Political Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
1	0	0	0	1	0	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.431	0.0862	0.2586	0.1897	0.0345		
	Amphib	Rank:	1	4	2	3	5		
		Output:	0.431	0.0862	0.2586	0.1897	0.0345		
	Airborne	Rank:	1	4	2	3	5		

Table 7. Fixed Economic Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
1	0	0	0	0	1	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.3438	0.1563	0.2188	0.25	0.0313		
	Amphib	Rank:	1	4	3	2	5		
		Output:	0.3438	0.1563	0.2188	0.25	0.0313		
	Airborne	Rank:	1	4	3	2	5		

Table 8. Fixed Social Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0	1	1	0	0	0	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.3626	0.2798	0.2184	0.0655	0.0737		
	Amphib	Rank:	1	2	3	5	4		
		Output:	0.3626	0.2798	0.2184	0.0655	0.0737		
	Airborne	Rank:	1	2	3	5	4		

Table 9. Unit Military Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0	1	0	1	0	0	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.3544	0.3141	0.1832	0.0698	0.0785		
	Amphib	Rank:	1	2	3	5	4		
		Output:	0.3544	0.3141	0.1832	0.0698	0.0785		
	Airborne	Rank:	1	2	3	5	4		

Table 10. Unit Political Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0	1	0	0	1	0	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.3674	0.3424	0.1284	0.0761	0.0856		
	Amphib	Rank:	1	2	3	5	4		
		Output:	0.3674	0.3424	0.1284	0.0761	0.0856		
	Airborne	Rank:	1	2	3	5	4		

Table 11. Unit Economic Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
α1	α2	β1	β2	β3	β4	γ1	γ2	γ3	γ3
0	1	0	0	0	1	1	0	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.2354	0.2228	0.1975	0.162	0.1823		
	Amphib	Rank:	1	2	3	5	4		
		Output:	0.2354	0.2228	0.1975	0.162	0.1823		
	Airborne	Rank:	1	2	3	5	4		

Table 12. Unit Social Value Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
α1	α2	β1	β2	β3	β4	γ1	γ2	γ3	γ3
0.5	0.5	0.25	0.25	0.25	0.25	0	1	0	0
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.4722	0.3194	0.4167	0.6389	0.5417		
	Amphib	Rank:	3	5	4	1	2		
		Output:	0.4722	0.3194	0.4167	0.6389	0.5417		
	Airborne	Rank:	3	5	4	1	2		

Table 13. Strategic Output

2. Additional Coefficient Analysis

After confirming that the algorithm behaves properly at the extreme values for the coefficients, additional runs of the algorithm were made to further investigate the generated rankings in different situations. Initially, a set of weights that assigns equal preference for all the equations were used. The original detection probabilities and the utility curve exponents were not changed for this example. Using this balanced set of priorities, the resulting rankings are: Node D, Node A, Node C, Node 1, and then Node B (Table 14).

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0.5	0.5	0.25	0.25	0.25	0.25	1	1	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	1.5967	1.3061	1.4745	1.6691	1.3147		
	Amphib	Rank:	2	5	3	1	4		
		Output:	1.5996	1.3113	1.4723	1.6632	1.3148		
	Airborne	Rank:	2	5	3	1	4		

Table 14. Equal Weight Output

The choice of Node D seems reasonable despite having only one infrastructure target present because there are only two regular infantry brigades available for its defense. Node D is also the closest objective to the strategic objective which increases its desirability over the others. The next best choice, Node A, was the heavily concentrated node. The higher static and unit values are offset by the higher defensibility parameter. Node B was heavily defended and had little value so its lowest preference is as anticipated. The only unanticipated result was Arc 1, which was ranked fourth ahead of Node B. There was no

infrastructure target on the arc, but the relative value of the infantry brigade compared to its own defenses was more important than the units on Node B, even with the bakery present.

If a maneuver commander were to focus only on enemy combat forces, then the unit military value and its defenses would be the only concerns. The set of coefficients representing this priority scheme produce the outputs given in Table 15. The ranking of target areas is : Node A, Node B, Node C, Node D, and Arc 1. The differences between the values are relatively small and bring into consideration the importance for establishing criteria for determining the importance of the difference between the values.

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0	1	1	0	0	0	1	0	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	1.1043	1.0741	1.0579	0.9837	0.7799		
	Amphib	Rank:	1	2	3	4	5		
		Output:	1.1071	1.0793	1.0557	.9778	.7801		
	Airborne	Rank:	1	2	3	4	5		

Table 15. Unit Military Value and Defensibility Output

In this case, the three highest values are within 5% of each other. There are two ways to handle this situation. The first would be to conclude that any of the three are equally preferred and all three should be nominated for further planning. While this may more be time consuming for the model, the result may be separate attrition estimates that more clearly delineate a single objective. The alternative would be to conclude that since no clear advantage exists, the algorithm should not nominate any objective until there are significant differences between the output values. Logically, for any number of units, the

military value, which comes from the equipment only, will be counteracted by the defensive capability of that same equipment. This explains why the outcomes are similar and a clear decision is not immediately obvious.

3. Detection Probability Analysis

The formulation of the defensibility parameter for each node or arc depends somewhat on the accuracy of the sensor (P_d) assigned. As discussed earlier, the model computes the expected asset count and the variance of that estimate in order to compute the perception probabilities for unit combinations in the target area. The variance of the number of assets represents the uncertainty of the information provided from the sensor and should be considered when determining the objective. As the probability of detection decreases, the variance increases. This will drive the upper limit of the estimate of the assets higher, causing an decrease in the defensibility parameter. This, in turn, would make the target area less desirable – a result consistent with the idea that uncertainty is generally unappealing in decision making. Tables 16 shows the results of decreasing the detection probability of Node D to 0.3 using defensibility as the only input (γ_3 = 1.0).

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0.5	0.5	0.25	0.25	0.25	0.25	0	0	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.8	0.8	0.8	0.3	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.7435	0.7958	0.8407	0.9118	0.7083		
	Amphib	Rank:	4	3	2	1	5		
		Output:	0.7469	0.8014	0.8388	0.9039	0.7091		
	Airborne	Rank:	4	3	2	1	5		

Table 16. Detection Probability Output

The ranking of the nodes did not change and, more surprisingly, the final utility output values changed only very slightly. The minimal effect is most likely a result of two conditions. First, Node D has the least military equipment present even when Arc 1's brigade is included. The increase in estimated numerical strength on Node D (from Equation 19) has little impact on the percent of total defenses and the final utility output value. Second, the anticipated impact of this uncertainty may be larger than the true, statistical impact. The algorithm computes the 95% upper confidence limit of the estimated number of assets on a given node. The difference between a higher detection probability of 0.8 and a lower one of 0.3 would clearly produce numerical differences, but these differences do not have substantial impact on the full computation of desirability.

An operational decision maker might completely rule out a potential objective if he was aware of the high level of uncertainty. This consideration is tied to a sense of reliability of the sensor. If there is not enough reliable information, a commander may decide there is too much risk in the unknown situation and avoid it altogether. The statistical techniques in the algorithm account for the errors, regardless, and in the final analysis, the values do not change significantly given the weights and utilities used.

To further investigate these results, extreme values of the detection probabilities were used to see if significant changes in the total utility output values or, possibly, a change in ranking would be observed. Table 17 shows the result of using a detection probability for Node D of 0.01 while the others were set at 0.99. While the rankings did not change, the final utility output values change noticeably from those in Table 16. Recognizing that any change in Node D's defensibility may not greatly affect the total defensibility in the 5 network elements, the same process was done using Node A, which has almost half of the test network's assets located on it.

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
$\alpha 1$	$\alpha 2$	$\beta 1$	$\beta 2$	$\beta 3$	$\beta 4$	$\gamma 1$	$\gamma 2$	$\gamma 3$	$\gamma 3$
0.5	0.5	0.25	0.25	0.25	0.25	0	0	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.99	0.99	0.99	0.01	0.99		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.75902	0.80955	0.85132	0.8554	0.7247		
	Amphib	Rank:	4	3	2	1	5		
		Output:	0.76656	0.81824	0.85243	0.83245	0.73031		
	Airborne	Rank:	4	3	2	1	5		

Table 17. Extreme Detection Probabilities Output

The results from changing Node A's detection probability are shown in Table 18. Again, although the output utility values changed somewhat, the rankings did not change for either the amphibious or the airborne/air mobile missions. Node A became close to Arc 1, and further analysis showed that had the detection probability gone below 0.28736 for the amphibious mission or 0.280718 for the airborne/air mobile mission, that the rankings would have switched. As shown in Table 19, when an extreme set of detection probabilities was used where Node A's was 0.01 and the rest were 0.99, the values changed even more drastically and Node A's ranking, as expected, changed accordingly to make it the least preferred target area.

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
α1	α2	β1	β2	β3	β4	γ1	γ2	γ3	γ3
0.5	0.5	0.25	0.25	0.25	0.25	0	0	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.3	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.71735	0.80111	0.84477	0.92092	0.71585		
	Amphib	Rank:	4	3	2	1	5		
		Output:	0.71891	0.80647	0.84286	0.91531	0.71646		
	Airborne	Rank:	4	3	2	1	5		

Table 18. Node A Detection Probability Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
α1	α2	β1	β2	β3	β4	γ1	γ2	γ3	γ3
0.5	0.5	0.25	0.25	0.25	0.25	0	0	1	1
								Amphib	Airborne
					Util Pwr	1	1	1	1
		P det:	0.01	0.99	0.99	0.99	0.99		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	0.55282	0.84787	0.88124	0.93799	0.78009		
	Amphib	Rank:	5	3	2	1	4		
		Output:	0.54699	0.85385	0.88134	0.93468	0.78314		
	Airborne	Rank:	5	3	2	1	4		

Table 19. Node A Extreme Detection Probabilities Output

4. Utility Power Analysis

The final modification to the input parameters measured the effects of changing the powers of the utility equations for value, strategic importance, and defensibility. As discussed in Chapter 3, it is unlikely that an operational decision maker would make decisions based on linear utility. It is reasonable to assume that the utility equation for the overall value of a target area could be considered "risk adverse" because increases in the lower range of value parameter are more important than corresponding increases at the higher values. This represents the operational decision maker's desire to engage target areas with sufficient value to make the mission worth the effort involved.

As mentioned previously, an added benefit of a risk adverse utility function will be the discrimination between relatively low values. The percentages of value should be of the order of magnitude of the inverse of the total number of nodes, assuming the value is spread relatively uniformly across the target areas of interest. For example, if there are ten nodes and arcs to be included in the calculations, the value percentages should be close to 0.1. For this small scenario, the average normalized value is 0.20 (for 5 areas, 1/5) with values usually ranging from about 0.05 up to about 0.4, so using a square root utility equation (utility power = 0.5) would expand the range from about 0.2 up to about 0.65.

The utility for the strategic importance parameter should have the opposite characteristics since the larger the strategic value gets, the closer the target is to the strategic objective. The reason for a "risk preferring" form for the utility function is driven by the desire to be as close as possible to the strategic objective (high values for Strategic Importance parameter) while distances that are significantly far away (small values) may be regarded as roughly equally preferred. This implies the utility power for the Strategic Objective should be greater than 1.0 and for this trial, it is chosen to be 2.0.

Lastly, the defensibility of the target areas follows the same logic as the value parameter considering the range of the percentage values. By subtracting the percentage of defensibility from 1.0, however, the importance of the higher values becomes more significant and the utility can also be considered risk preferring, since increases in higher values are more preferred than increases in lower values. This represents the desire of the operational decision maker to minimize the potential threat posed at the target area. As the threat levels increase substantially, the risk to his forces becomes so great that they all become undesirable.

The use of a risk preferring utility curve, where the power of the utility equation is greater than 1.0, also expands the output values of defensibility utility in the most common range of values. In this case, however, the values are in the region of 1.0 minus the reciprocal of the number of potential target areas. For this example, the values should be close to 0.8 (1 - 1/5) and in fact, the range of values is from 0.7062 to 0.9182 . Using a utility power equal to 3.0 further expands the range from 0.3522 to 0.7741.

The initial run with the utility powers of 0.5, 2.0, and 3.0 produced the output ranking of : Node D, Node A, Node C, Node B, and then Arc 1 (Table 20). The coefficients used represent concern for all value types with an emphasis on the unit military value, which attempts to simulate a CINC's concern with all parameters, but with a focus on the enemy forces. The ranking shows Node D to be the clearly preferred objective with Nodes A and C very close in second and third.

The impact of changing the probability of detection of Node A to 0.5 from this point is seen in Table 21. The increase in variance caused Node A to drop below Node C in preference. The magnitude of the change in final output utility numbers is small; however, this rank change will only be seen if two nodes or arcs are almost the same initially.

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
α1	α2	β1	β2	β3	β4	γ1	γ2	γ3	γ3
0.25	0.75	0.4	0.2	0.2	0.2	1	1	1	1
								Amphib	Airborne
					Util Pwr	0.5	2	3	3
		P det:	0.8	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	1.2355	1.08951	1.2229	1.51075	0.93004		
	Amphib	Rank:	2	4	3	1	5		
		Output:	1.24029	1.09939	1.21815	1.4958	0.93023		
	Airborne	Rank:	2	4	3	1	5		

Table 20. Preliminary Utility Output

Fixed	Unit	Military	Political	Economic	Social	Value	Strategic	Defense	Defense
α1	α2	β1	β2	β3	β4	γ1	γ2	γ3	γ3
0.25	0.75	0.4	0.2	0.2	0.2	1	1	1	1
								Amphib	Airborne
					Util Pwr	0.5	2	3	3
		P det:	0.5	0.8	0.8	0.8	0.8		
			Node A	Node B	Node C	Node D	Arc 1		
		Output:	1.2159	1.0958	1.2284	1.5141	0.9372		
	Amphib	Rank:	3	4	2	1	5		
		Output:	1.2195	1.1059	1.2240	1.4995	0.9378		
	Airborne	Rank:	3	4	2	1	5		

Table 21. Node A Detection Probability and Utility Power Output

An important concern is the impact of the utility power on the final rankings. By varying them one at a time and leaving the other two at their initial values, some trends or points of interest may be observed. If only one of the three utility parameters (value, strategic importance, or defensibility) is used, the rankings will not change because the utility function is increasing (as long as the power is positive); thus at least two of the three must be used to investigate any significant results. Varying the value utility power from

0.05 to 1.0 in increments of 0.05 produced the rankings shown in Table 22. There was a change in ranking for the amphibious mission between 0.35 and 0.40 and for the airborne/ air mobile mission between 0.40 and 0.45. Although, in neither case was the first choice changed, the possibility remains that it could change if the highest output utility values were similar. This further amplifies the need for some threshold of difference between values in order to properly distinguish objective priorities between two close output utility values. The threshold could be a function of the values themselves, the power used in value utility, and the number of elements considered.

Utility Power	Amphib Rank	Airborne Rank	Remarks
0.05	D, C, A, B, 1	D, C, A, B, 1	
0.10	D, C, A, B, 1	D, C, A, B, 1	
0.15	D, C, A, B, 1	D, C, A, B, 1	
0.20	D, C, A, B, 1	D, C, A, B, 1	
0.25	D, C, A, B, 1	D, C, A, B, 1	
0.30	D, C, A, B, 1	D, C, A, B, 1	
0.35	D, C, A, B, 1	D, C, A, B, 1	
0.40	D, A, C, B, 1	D, C, A, B, 1	Change Amphib
0.45	D, A, C, B, 1	D, A, C, B, 1	Change Airborne
0.50	D, A, C, B, 1	D, A, C, B, 1	
0.55	D, A, C, B, 1	D, A, C, B, 1	
0.60	D, A, C, B, 1	D, A, C, B, 1	
0.65	D, A, C, B, 1	D, A, C, B, 1	
0.70	D, A, C, B, 1	D, A, C, B, 1	
0.75	D, A, C, B, 1	D, A, C, B, 1	
0.80	D, A, C, B, 1	D, A, C, B, 1	
0.85	D, A, C, B, 1	D, A, C, B, 1	
0.90	D, A, C, B, 1	D, A, C, B, 1	
0.95	D, A, C, B, 1	D, A, C, B, 1	
1.00	D, A, C, B, 1	D, A, C, B, 1	

Table 22. Value Utility Sensitivity Analysis

The sensitivity analysis done for the Strategic Objective parameter produced the resulting rankings in Table 23 by varying the utility power from 1.0 to 3.0 in increments of 0.10. There was no rank change for the airborne/air mobile mission, but the amphibious mission had a change at 2.80 where this time, the second most preferred node changed from Node A to Node C. The result shows little impact in the range of the initial value of 2.0 for this scenario.

Utility Power	Amphib Rank	Airborne Rank	Remarks
1.00	D, A, C, B, 1	D, A, C, B, 1	
1.10	D, A, C, B, 1	D, A, C, B, 1	
1.20	D, A, C, B, 1	D, A, C, B, 1	
1.30	D, A, C, B, 1	D, A, C, B, 1	
1.40	D, A, C, B, 1	D, A, C, B, 1	
1.50	D, A, C, B, 1	D, A, C, B, 1	
1.60	D, A, C, B, 1	D, A, C, B, 1	
1.70	D, A, C, B, 1	D, A, C, B, 1	
1.80	D, A, C, B, 1	D, A, C, B, 1	
1.90	D, A, C, B, 1	D, A, C, B, 1	
2.00	D, A, C, B, 1	D, A, C, B, 1	
2.10	D, A, C, B, 1	D, A, C, B, 1	
2.20	D, A, C, B, 1	D, A, C, B, 1	
2.30	D, A, C, B, 1	D, A, C, B, 1	
2.40	D, A, C, B, 1	D, A, C, B, 1	
2.50	D, A, C, B, 1	D, A, C, B, 1	
2.60	D, A, C, B, 1	D, A, C, B, 1	
2.70	D, A, C, B, 1	D, A, C, B, 1	
2.80	D, C, A, B, 1	D, A, C, B, 1	Change Amphib
2.90	D, C, A, B, 1	D, A, C, B, 1	
3.00	D, C, A, B, 1	D, A, C, B, 1	

Table 23. Strategic Importance Utility Sensitivity Analysis

The final sensitivity analysis was done by varying the defensibility utility power from 1.0 to 4.0 in increments of 0.2 and the results are presented in Table 24. There was no change in the rankings and only nominal changes in the output utility values.

Utility Power	Amphib Rank	Airborne Rank	Remarks
1.00	D, A, C, B, 1	D, A, C, B, 1	
1.20	D, A, C, B, 1	D, A, C, B, 1	
1.40	D, A, C, B, 1	D, A, C, B, 1	
1.60	D, A, C, B, 1	D, A, C, B, 1	
1.80	D, A, C, B, 1	D, A, C, B, 1	
2.00	D, A, C, B, 1	D, A, C, B, 1	
2.20	D, A, C, B, 1	D, A, C, B, 1	
2.40	D, A, C, B, 1	D, A, C, B, 1	
2.60	D, A, C, B, 1	D, A, C, B, 1	
2.80	D, A, C, B, 1	D, A, C, B, 1	
3.00	D, A, C, B, 1	D, A, C, B, 1	
3.20	D, A, C, B, 1	D, A, C, B, 1	
3.40	D, A, C, B, 1	D, A, C, B, 1	
3.60	D, A, C, B, 1	D, A, C, B, 1	
3.80	D, A, C, B, 1	D, A, C, B, 1	
4.00	D, A, C, B, 1	D, A, C, B, 1	

Table 24. Defensibility Utility Sensitivity Analysis

D. SUMMARY OF RESULTS

The initial results for the rankings with only one parameter of interest were all consistent with "common-sense" analysis of each situation. The military focus of the initial utility outputs (Table 20) produced the output ranking of Node D, Node A, Node C, Node B, and Arc 1 which seems consistent with conventional military wisdom. With the exception of Arc 1 being least preferred, this order of preference is what was anticipated when the scenario was created. In retrospect, however, Arc 1 being least preferred is entirely consistent with the algorithm and how it was intended.

Changing the probability of detection exhibited much less impact on the outcome values than was expected. In this test scenario, the probability of detection assumes that there will exist a definite detection opportunity. Two issues arise from this situation. The sensor may not be capable of detecting any assets if there is bad weather or battlefield obscuration. In these cases, no detections would be made and no inferences could be made on that pass alone. The model, however, will still have the information from previous passes. There will be an increase in the variation of a new estimate based on older sensor information as it is discounted for the time elapsed. During this time, units may have entered or exited the target area so it is difficult to make an accurate prediction of the assets. It makes sense that the example, which had detection with a known probability, had lower than expected impact of increased variability in the perceived defenses around the objective.

This use of prior information is not available to the algorithm in this test scenario. Instead, the approximation to the variance of the estimated number of combat assets, $\hat{N}$, is computed from the binomial approximation to the distribution of detections using P_d. This method does not seem to produce the necessary increase in the upper confidence limit of the estimated number of assets on and around the objective to substantially change the output utility values unless the detection probability is unrealistically low.

The sensitivity analysis portion showed a potentially noticeable impact on the output ranking when the value utility power was varied near the proposed value of 0.50. The two output utility values for Node A and Node C are quite close in the initial utility outcomes. For the strategic importance and defensibility, the changing of the utility powers caused little change, and then only well beyond the proposed values of 2.0 and 3.0, respectively.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The challenge in modeling a decision making process in a combat model lies primarily in the identification of information available and the appropriate use of it. In a theater level conflict there will be a wide variety of information available to the operational decision maker and his staff. The knowledge and experience that each brings with them will affect how they use the information and the decisions ultimately made. Modeling the planning and execution of campaign missions should first represent as much of the available information as possible and then make decisions using it. The impact of the available information is not always easy to discern or duplicate mathematically in a combat model.

The algorithm presented is the first step in incorporating some of the strategically significant aspects of a campaign that are not generally included in combat simulations. Computer models have traditionally omitted the other-than-combat aspects of a theater level conflict. The probable reasons are the initial difficulty in assigning numerical values to concepts such as political impact and social significance and the equally daunting task of then using these numbers properly. The subjectivity of both the assignment of the values and their relative importance in the decision making processes does not mandate that these factors be overlooked, rather it should demand further investigation. It is obvious that there will be factors other than purely military ones that shape the decisions made at the theater level.

By adding the additional value parameters, as well as elements in the network that possess them, JWAEP will continue to move away from traditional combat models. As discussed in Chapters 3 and 4, the challenge will be the appropriate use of these proposed additions.

The initial results of the algorithm to evaluate the relatively small network seemed acceptable. Each different combination of weights assigned to the input parameters produced seemingly realistic and logical results. Varying other parameters used in the algorithm resulted in the appropriate changes to the output utility values and the objective rankings. Having demonstrated that the basic approach and methodology yield acceptable results, the algorithm can be incorporated into JWAEP for further analysis in larger scenarios.

B. FUTURE DEVELOPMENT

1. Algorithm Refinements

When the algorithm is incorporated into the JWAEP model, the larger size of the network may produce large sets of nodes and arcs to analyze. The resultant percentage calculations will have a tighter grouping in the very low range. The coefficients and utility powers may need to be modified to overcome the clustering effect this may have. One possible solution may be to multiply each percentage calculation by the number of eligible nodes and arcs in order to bring the numbers into more reasonable ranges. Additionally, a larger number of potential objectives may increase the chances for output values that are closer together and do not produce a clear preference. The examination of a threshold difference between two objectives will become very important.

As the aggregated strength variables mature, they can be included in the calculation of the military value of a unit. Instead of adding up only the firepower scores, future versions may be able to account for the unit's entire military capability. These strength variables should also then be used in the calculation of defensibility. The aggregated strength variables could be expanded further to include the "intangible" aspects of a unit such as training, experience, morale, cohesion, and leadership. These play a significant part in a unit's performance in battle and, like the non-military value parameters in the

theater model, they may be difficult to account for but should not be wholly ignored. These characteristics should be dynamic during the execution of the model; how the values change could be related to success in battles, heavy losses, new replacements, etc. These proposed changes, however, depend on the representation of specific individual units which can be identified by the opponent, not just unit types.

Future refinements should include a more detailed determination of the strategic importance of the objective. The method presented does not relate the importance of a given target area to the course of action (COA) probabilities, and this certainly will affect a potential objective's importance. There may be synergistic effects of tactical importance (seen in the inherent military value of a target area) with the COA probabilities which could represent the importance of critical terrain such as a choke point on an enemy avenue of advance or a crucial supply route which supports an enemy defensive position.

The defensibility parameter could include only those units which can actually travel to the objective in a given interval of time rather than just the fixed distance that the algorithm uses currently. Once in JWAEP, it should be easy to invoke the shortest path algorithms and use the travel rates and terrain types to determine if a unit can, in fact, get there in time to assist in defending against the assault. In general it seems more appropriate to determine distance limits based on the time expected to travel rather than just the distance alone.

There is the possibility that the presence of a particular type of unit can pose a higher threat to the assault force than its firepower score may indicate. For example, a medium altitude air defense missile battery may prohibit an airborne assault on a certain objective. The current process of excluding weapon systems if they do not pose a direct threat to the assault force could be expanded with either specific criteria that prohibit inclusion of that particular objective (like the objective with the missile battery for the airborne mission) or the impact of the unit could be magnified by using a multiplicative

factor to drive the defensibility higher, representing the greater desire to avoid that objective.

In the spreadsheet model, the defensibility parameter's variances were determined largely from the probabilities of detection for each target area and did not use any part of the prior information that would normally be available in JWAEP. Better use of the more sophisticated information available in the model could modify this initial attempt to use uncertainty in selecting objectives. Additionally, the incorporation of the uncertainty of the defensibility would benefit from the proposed modification to degrade the estimates of the asset counts produced by the sensors over time. During the execution of the model, the variance will increase if there are not timely subsequent sensor passes for the Bayesian updating process. This captures the essence of "old" intelligence versus "current" intelligence. The exact method to accomplish this has not been determined but the effect of aging intelligence estimates in terms of reliability might be used to increase the impact of the uncertainty calculations on the output rankings of the algorithm.

The utility equations in the final steps of the algorithm need more refinement, perhaps by actually interviewing former operational decision makers to construct them. The ones used reflect one group of values which seemed reasonable to the author. Much more work can be done to make them as reasonable as possible for each parameter.

Finally, the algorithm, like all of the decision making processes in JWAEP, must address one of the single most important aspects of military operations — timing. The importance of timing missions in order to maximize their effect on the enemy makes it imperative to somehow incorporate it into any mission planning logic. For small tactical skirmishes, a "fast as possible" attitude can be assumed; at the campaign level it most certainly cannot. The principles of speed and surprise must be considered, but coordination and timing are just as important.

2. Algorithm Extensions

The algorithm presented could be used for other decision making processes in the combat model by using certain combinations of coefficients. For example, the algorithm could be used to choose tactical objectives for smaller engagements by considering only the defensibility parameter. Since the defensibility parameter is based solely on enemy assets and their effect on a particular friendly force type, the algorithm could identify perceived surfaces and gaps in the enemy's array of forces.

A method could be developed to use the algorithm to analyze friendly forces to find their weaknesses and strengths. This might indicate how to better array our forces to defend ourselves in a particular situation and, at the same time, attempt to predict the actions of the enemy by essentially putting ourselves in his shoes and seeing how we think we look to him. However, the mechanism for the asset counts and expected number or types of friendly units would have to rely on our internal command, control, and communications capabilities and not from sensors. An operational decision maker will not always know the disposition or location of his subordinate units during periods of heavy activity and this uncertainty could be incorporated in evaluating our own abilities.

A different extension of the algorithm could be used to assign initial targeting priorities. The value parameter alone could provide an ordered list of the infrastructure and operating areas in the enemy's control. Difficulties would arise in trying to target enemy units unless the issue of unit identification is addressed so they could be tracked and engaged individually. However, the static target list could be further refined by applying defensibility calculations to the perceptions of specific enemy unit types. For example, by comparing the value to just enemy air defense units, the algorithm can provide initial air targeting input for the more detailed planning and execution modules which would then evaluate the mission feasibility, attrition estimates, and the like. Those targets heavily

defended against air strikes might then be nominated for engagement by long range indirect fire units. The perceived type of air defense might help push the mission to the strategic bombing aircraft like the B-1 instead of the tactical aircraft such as the F/A-18 used by the aircraft carriers.

The algorithm's use of value, importance, and defensibility to select objectives for forced entry missions is generalizable to many situations where decisions require the comparison between value and risk as they are present in combat. From this initial attempt, future work can strive to improve the creation of the value assignments, the determination of coefficients values and the use of the utility equations.

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